Appendix L

Post Flood Report

U.S. Army Corps of Engineers
Memphis District

Mississippi River and Tributaries System

2011 Post-Flood Report

Documenting the 2011 Flood, the Corps' response, and the performance of the MR&T System

December 2012

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MISSISSIPPI RIVER COMMISSION
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VICKSBURG, MISSISSIPPI

December 21, 2012

The Mississippi River and Tributaries (MR&T) project is perhaps the world's most comprehensive and successful flood risk management and navigation systems. More than a dozen significant floods have tested the MR&T since its inception over 80 years ago, but none as extensively as the 2011 record flood. In 2011, the MR&T system performed as designed by accommodating the river while using roughly 85 percent of its overall design capacity. Even though this was the largest Mississippi River flood in recorded history, astonishingly not a single life was lost. An incredible $230 billion in flood damages were prevented in that single event. Since its inception, the MR&T system is calculated to have prevented $612 billion in cumulative flood damages. At an investment level of $14 billion, those savings result in a $44 return on every $1 invested. These figures do not include all of the positive economic activity, from farming to towns and factories, plus annual transportation savings of $3 billion enabled by this unique system.

We owe a debt of gratitude for the wisdom, tenacity, and efforts of our fore-bearers who envisioned, devised, funded, constructed, and maintained this innovative system that has proven so beneficial to so many for so long. We extend our sincere appreciation to the thousands of local landowners, levee boards, cities, states, and other partners who determinedly fought the flood alongside us and who continue to stand with us during the path to recovery. The region and the nation are grateful beneficiaries of those endeavors.

After more than a year of evaluation and documentation, the expansive MR&T 2011 Post Flood Report and the condensed *"Room for the River"* booklet will serve as educational tools and reference points for our citizens, decision makers, and future flood fighters. Facts, figures, and lessons derived from the 2011 flood serve to hasten and guide our efforts to rebuild and improve the MR&T project, ensuring the continued safety and security of our citizen's lives and livelihoods.

The U.S. Army Corps of Engineers and Mississippi River Commission, working hand-in-hand with our strong partners, continues to study the lessons from past history, apply those lessons to maintain and improve the system in the present, and collaborate with all partners and stakeholders to envision and craft an improved and more resilient future. We continue to be generational beneficiaries of the world's most commercially vibrant watershed and its largest inland navigation system, with an incredibly diverse natural ecological treasure, all enabling the nation's economic and natural vitality.

Essayons and Building Strong!

John W. Peabody
Major General, U.S. Army
Commander, Mississippi Valley Division
President, Mississippi River Commission

MISSISSIPPI RIVER AND TRIBUTARIES SYSTEM

2011 POST-FLOOD REPORT

DECEMBER 2012

US Army Corps of Engineers®
Mississippi Valley Division
New Orleans District
Vicksburg District
Memphis District
St. Louis District
Rock Island District
St. Paul District

COVER PHOTOS

Background Photo: MR&T System Levee holding back 2011 flood waters 20 miles west of New Orleans, LA

Upper Inset Photo: Old River Control Complex on May 14, 2011

Middle Inset Photo: Maj. Gen. John W. Peabody (left) and Maj. Gen. Michael J. Walsh being briefed on 2011 flood conditions near Cairo, IL

Lower Inset Photo: Flooding near Yazoo City, MS

REPORT CITATION

Mississippi River and Tributaries System 2011 Post-Flood Report, Henry DeHaan, Jeffery Stamper, Bret Walters, et. al., USACE, Mississippi Valley Division, December, 2012

The primary source of the MR&T background information provided in this report is the information paper, *The Mississippi River and Tributaries Project: Controlling the Project Flood*, Mississippi River Commission, 2007

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MISSISSIPPI RIVER AND TRIBUTARIES SYSTEM

2011 POST-FLOOD REPORT

FOREWORD

In response to the historic flooding experienced in 2011, the US Army Corps of Engineers (Corps), Mississippi Valley Division (MVD) has prepared this Post-Flood Report (PFR) to document the operation and performance of Mississippi River and Tributaries (MR&T) flood risk management system. This comprehensive internal assessment evaluates the performance of individual MR&T System components and how well the individual components were utilized and operated as a system to manage the complex set of risks presented by the 2011 Flood. The report concludes with recommendations for improvements and future studies to aid MR&T recovery efforts and future system operation, management, and flood fight activities.

The MR&T System 2011 PFR has been prepared by a multi-disciplinary Corps team in accordance with Engineering Regulation 1110-2-240 *Water Control Management* and ER 500-1-1 *Civil Emergency Management Program*. Corps Headquarters and the MVD senior leadership also provided additional guidance and oversight.

The primary products generated through the effort include this MR&T System 2011 PFR with supporting appendices and a Summary Report entitled *Room for the River* that briefly captures the most important facts and findings from the PFR. This PFR and appendices provide detailed technical information and recommendations related to the operation and management of the system and is intended for MR&T decision makers, managers, flood fighters; and Federal and State agency flood risk management partners. The Summary Report presents a clear and concise synopsis of the main Post-Flood Report and will provide decision makers, stakeholders and the public with a good understanding of the overall performance of the MR&T in 2011 and the overarching recommendations for improving future flood risk management within the system.

A thorough, multi-stage review of the PFR was conducted from June 2012 through November 2012. The report underwent an interim District Quality Control review by a team of reviewers comprised of members from all six MVD Districts as well as reviews by Corps District, Division, and HQ senior leaders and staff. Information completeness and accuracy was the focus of these reviews to assure a quality product was generated for the intended audiences.

This effort has endeavored to support and coordinate with similar efforts being performed in response to 2011 Flood events in Northwest Division, Great Lakes and Ohio River Division, Southwestern Division, as well as the OPORD 2011-50 Greater Mississippi Basin System Performance Assessment being conducted by Corps Headquarters. Partnership and coordination has also occurred and will continue with partners agencies (e.g., USGS and the NWS) on their comparable efforts focused on improving future Mississippi River Basin flood risk management efforts.

MISSISSIPPI RIVER AND TRIBUTARIES SYSTEM

2011 POST-FLOOD REPORT

EXECUTIVE SUMMARY

This Mississippi River and Tributaries (MR&T) System Post Flood Report (PFR) presents the results of a comprehensive internal assessment of the performance of the MR&T System during the historic 2011 Flood. It documents the results of assessments of individual MR&T System components and how well these components were utilized and operated as a system to manage the complex set of risks presented by the 2011 Flood.

This report was generated as a part of Operation Watershed – Recovery, a much broader effort comprised of a wide range of activities performed by the Mississippi Valley Division and its partners in response to the 2011 Flood. It focuses on answering three primary questions:

1. **How did the MR&T System perform in 2011?**
2. **How could the MR&T System perform in its post-flood condition?**
3. **What does the MR&T System need to perform in the future?**

In addition to answering those questions, the report documents information useful for system management decisions, operations, and improvements, and is expected to serve as a useful reference for flood risk management (FRM) efforts elsewhere. The report also describes preparation, and response actions and management decisions made before, during, and after the 2011 Flood. It also provides the contextual information needed to understand how the entire MR&T System was used to mitigate risks, how it performed during the 2011 Flood, and what is needed to prepare the system for future flood events. The report concludes with preliminary recommendations for improvements and future studies to aid MR&T recovery efforts and future system operation, management, and flood fight activities. Although the report provides recommendations, it is not a decision or implementation document. Where a decision document would be needed to implement recommendations, studies to fully evaluate proposed changes and potential improvements will be required.

The MR&T System is one of the largest and most successful FRM systems in the world. It is comprised of an extensive and integrated system of levees; floodways to divert excess flows past critical reaches; backwater areas to store excess water during significant floods; and channel improvement and stabilization features to protect the integrity of FRM features and ensure proper alignment and depth of the navigation channel. Additionally, there are tributary basin improvements including levees, headwater reservoirs, and pumping stations that further reduce flood risks and improve drainage.

The 2011 Flood tested the MR&T System like no flood before; it was the largest recorded flood through much of the Lower Mississippi River. Stage and flow rates broke records at several locations, and for the first time, three floodways—Birds Point-New Madrid (BPNM) Floodway, the Morganza Floodway, and the Bonnet Carré Spillway—were all operated during a single flood event. River stages and flow rates were comparable to the major floods of 1927 and 1937. However, the 2011 Flood was contained within the MR&T System to a greater extent than the earlier comparable floods.

Figure ES-1 compares the areas inundated during the 1927 and 2011 floods. Figure ES-2 compares the river stages recorded during the 2011 Flood at the Red River Landing, LA with stages recorded during other historical floods.

Despite extensive damages to many MR&T components caused by the 2011 Flood, the MR&T System performed as designed and there were no recorded deaths attributed to the event. The Corps, in combination with many local and state partners performed extensive emergency flood fight measures. The typical emergency flood fight measures included ringing sand boils, constructing water berms, blocking culverts and ditches to prevent inflow of floodwaters, constructing erosion control measures, and raising deficient sections of the mainstem Mississippi River Levees to authorized grade. Although backwater effects occurred on several rivers, none of the MR&T authorized backwater areas were operated during the 2011 Flood because the backwater levees were not overtopped. No sections of the mainline or backwater levees were raised above authorized grade for purposes of the flood fight.

The 2011 Flood affected approximately 119 counties and parishes in portions of seven states. To estimate damages, economic analyses were conducted which utilized inundations generated from numerical hydraulic model outputs and other data to identify the types and locations of properties impacted and assessed the damages associated with these impacts. Three models, Hydrologic Engineering Center's River Analysis System Program, the Flood Event Simulation Model, and Hydrologic Engineering Center's Flood Impact Analysis Program, were utilized. The models were used to generate predicted inundation boundaries for three scenarios to compare to the actual inundation area associated with the 2011 Flood. The scenarios are summarized as follows:

Scenario 1 - the existing 2011 scenario as it occurred during the 2011 Flood (i.e., with levees and flood control reservoirs in place, including deviations to reservoirs' Operation Plans)

Scenario 2 - the scenario with no levees, but with flood control reservoirs (i.e. without levees and associated cutoffs but assuming all reservoirs are in place)

Scenario 3 - the scenario with no levees and no Federal flood control reservoirs (no levees, cutoffs, or Federal reservoirs)

Scenario 4 - the existing 2011 scenario without deviations or directives to flood control reservoirs' Operation Plans

Figure ES-3 shows the area that would have been inundated had the MR&T System not been present in 2011.

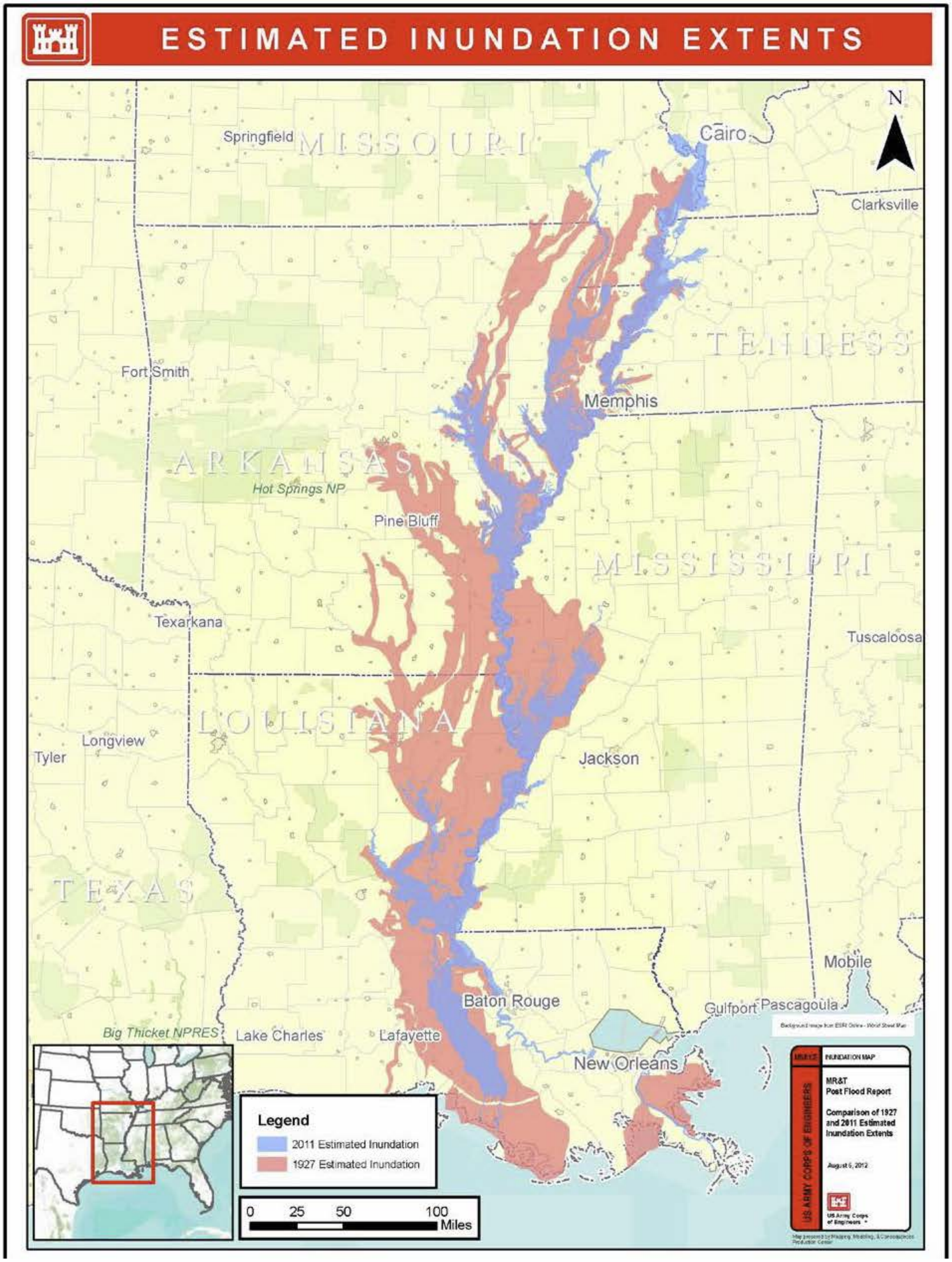

Figure ES-1. Comparison of Inundation During the 1927 and 2011 Floods

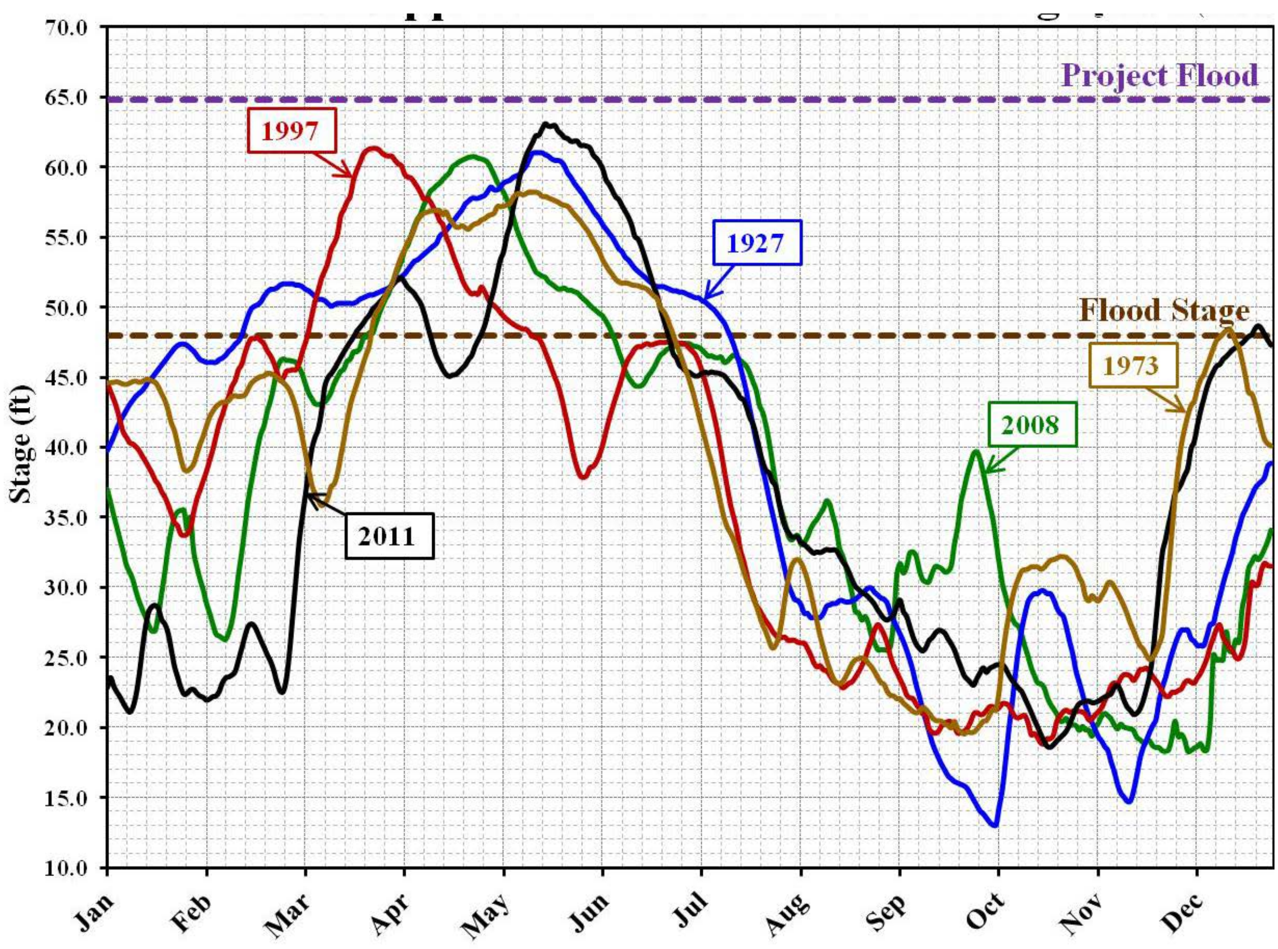

Figure ES-2. Mississippi River Hydrograph, Red River Landing, LA

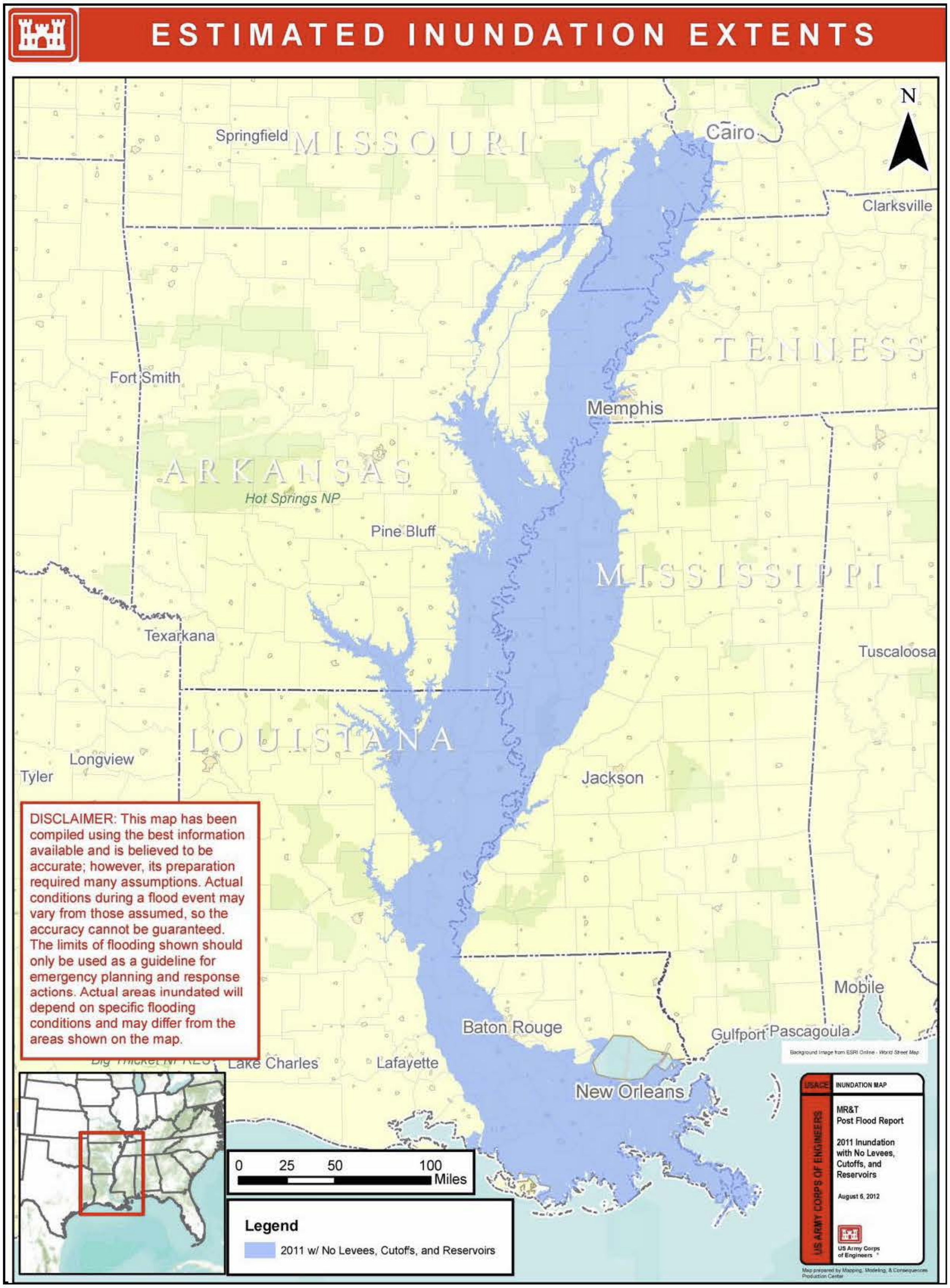

Figure ES-3. Inundation Area Created by Scenario 3 -Without Levees, Cutoffs, or Reservoirs

Based on the scenario analysis, the total economic flood damage from the 2011 Flood was estimated at $2.8 billion. Total flood damages without an FRM system in place (i.e., no MR&T) are estimated to exceed $237 billion. Overall, the MR&T System prevented approximately $234 billion in damages. Without a FRM system in place, approximately 1.5 million residential and commercial structures would have been impacted. With the MR&T System, the number of impacted structures was approximately 21,000.

In addition to the economic damages caused by the flood, many MR&T System components were damaged. Initial rough-order of magnitude damage cost estimates provided in early June 2011 before intensive damage assessments was in the range of two billion dollars. Nearly all of the levee/floodwall systems experienced some degree of damage from scour, erosion and seepage. The Channel Improvement Program identified a significant number of armored shorelines that sustained damage to Articulated Concrete Mattress revetment and numerous locations where dikes and other structures sustained damage. Excessive deposition of sediment mobilized by floodwaters was found in the main channel and ports/harbors. Scour and erosion related damage occurred during the operation of several water control structures and environmental and cultural resources were affected by the flood and operation of some MR&T System components.

In the midst of the 2011 Flood, MVD assembled a group of key Federal and state agencies in the form of an Interagency Recovery Task Force. The primary intent of this task force was to focus regional managers, leaders and decision maker's attention and resources on the challenges facing the flood recovery efforts. This task force met regularly for more than a year after the flood event to identify and address flood recovery challenges and issues.

Operation Watershed –Recovery was developed with a purposeful and intensive damage assessment protocol, regional prioritization of flood damages and an aggressive Flood Repair Plan. This protocol used detailed damage assessment information to order critical and noncritical repairs into four risk-based classes. The Operation Watershed – Recovery Flood Repair Plan focused on applying financial and human resources to the repair of critical high risk damages first. After these damages are addressed, work will then shift to less critical items and proceed until the MR&T System is restored back to pre-2011 Flood conditions.

"Immediate Critical Life Safety Repairs" were self-funded and initiated in summer and fall of 2011 to stabilize or repair 29 high risk damaged areas at a cost of $170 million. After passage of the Consolidated Appropriations Act in December 2011 which provided $802 million in supplemental funding for the MR&T repairs and receipt of additional funding from two other sources ($35 million FCCE, and $153 million Operation & Maintenance), the Corps was able to proceed with implementing an additional 118 "Critical Repair" projects needed to restore and prepare the system for the next high water event. The supplemental funding would also fund just over 100 of the 302 "Non-Critical Repair" projects that were identified and ranked through the MR&T damage assessment process. Completion of these repair efforts will reduce the current elevated flood risks to the system and restore the MR&T to pre-2011 Flood conditions. The remaining unfunded "Non-Critical Repair" projects will be addressed as funds from the annual Operation & Maintenance and MR&T budgets allow.

Most of the repair efforts are scheduled to be completed in 2012 and 2013. Completion of several complex "Critical Repair" projects will extend into later years (i.e., nine in 2015 and potentially one in 2016) primarily due to the magnitude of the required repairs and duration of the construction efforts. Some of the non-critical repairs (e.g. channel re-armoring) could extend out over the next several years depending on annual funding availability.

In developing this report, opportunities to better restore, sustain, and improve the MR&T System have been identified through the systematic assessment of its operational and structural performance during the 2011 Flood The assessment included an evaluation of key operational decisions associated with the Birds Point-New Madrid Floodway, Muddy Bayou Control Structure, Yazoo Backwater Levee, and Morganza Floodway. It also addressed the supporting information and the operational plans utilized in the decision-making process.

Based on a holistic view of the 2011 Flood and the performance of the MR&T System, the following conclusions may be drawn regarding the system:

- The 2011 Flood was one of the largest on record, particularly in the lower reaches of the Mississippi River.
- Although it was one of the largest floods, much of the extreme rainfall was concentrated, resulting in range of interior flooding issues including drought-like conditions on the lower end of the system.
- Flood fighting was a key measure during the flood. The Corps assigned approximately 1,000 staff to the flood and spent nearly $60M from March to August when Emergency Operations were underway.
- The flood fighting techniques employed at a tactical level were generally successful in maintaining the integrity of the primary FRM System. An exception is the construction of ring dikes around sand boils and seeps. Some locations reported the throat of the sand boil moving outside the ringed area and requiring re-ringing. This is typically caused by "bleed" channels located too high in the ring dike or missing entirely. The Flood Fight Manuals require updating to provide clearer instructions on ringing sand boils and overall flood fighting terminology and techniques.
- Tie-in issues (floodwall to high ground) have been studied and tested extensively in the aftermath of Hurricane Katrina, and recommendations for tie-in designs are available in the Corps Armoring Manual dated November 2011. As these recommendations are implemented, these types of problems should become less frequent.
- The operation of the MR&T System, as a whole, was adequate to minimize flood impacts. This includes the operation of gates, reservoirs, spillways, and diversions located throughout the System.
- There were 24 reservoirs utilized during the flood with only 5 of them being an MR&T component. The use of the 24 reservoirs ranged from simply monitoring conditions and reporting to normal control to deviation from normal control. Six of the reservoirs reached at least 100% of their flood control storage. Dam safety ratings of reservoirs influence their operation and could impact flood levels in the future.
- No significant breaches occurred in the primary FRM System. Minor breaches occurred in a private spur levee and as part of the operation of the New Madrid Bend Levee.
- Both MVK MR&T System segments were rated unacceptable (pre-flood) requiring extra diligence during 2011 flood fight operations. An "unacceptable" rating occurs when the condition of one or more components may prevent the system segment from performing as designed.
- One of seven MVM MR&T System segments was unacceptable (pre-flood). This increased to four systems post-flood.

- None of six MVN MR&T System segments were rendered unacceptable (pre or post flood).
- The system contains pre-flood deficiencies of which some were not tested by the flood and remain a risk. An example of such underlying/residual risks relates to the 11 percent of the MR&T System on-going construction efforts that may continue for decades.

These conclusions were used to develop a comprehensive and prioritized set of preliminary component-specific recommendations to address the weaknesses and vulnerabilities that were revealed by the 2011 Flood. The report divides these component specific recommendations into three overarching categories (strategic, operational, and technical) to help establish the most appropriate approach to advancing them.

The PFR effort identified several key overarching recommendations for the MR&T System. These overarching recommendations capture the main themes of the many detailed recommendations developed through this effort:

- **Use the information from the PFR effort to inform repair of the MR&T System.** Use 2011 MR&T System performance, damage, and risk assessment information developed through the PFR and other efforts to help establish appropriate repair processes. This includes efforts focused on improving levee resiliency, confirming level of protection, sharing best practices, and developing system repair plans using risk-informed decision making.
- **Use the information from the PFR effort to inform completion of the MR&T System.** Information from the PFR effort should be used to aid in the development of a plan to complete the remaining 11 percent of the MR&T System not yet constructed. Information that would provide insights into this include MR&T performance, changing river hydraulics, improved levee engineering, economics and associated risks, environmental and other stakeholder considerations.
- **Update Operation Plans/Manuals, Communications Plans, and SOPs using information from this PFR, external inputs, AARs, etc.** Use information developed through the PFR effort, AARs, external inputs, and further studies to inform the update and enhancement of MR&T operation and flood fight plans/manuals, SOPs and regionally standardized communication plans. These efforts would focus on improving both internal and external MR&T related operations during major flood events and would involve refinement of existing processes and utilization of new technologies. Example efforts may include enhancing flood fight operations with newly developed tools and examining the potential need to update operations plans for key MR&T FRM structures.
- **Regionally standardize communication approaches and products with MR&T System floodway and backwater area stakeholders.** Use feedback from stakeholders, lessons learned, best practices, and new technologies to develop regionally consistent communication approaches, tools and products to improve understanding, reduce impacts and improve collaboration during future floods. The Interagency Recovery Task Force offers great potential to make this a coordinated multi-agency effort.

- **Evaluate the need to conduct an updated flow line study for the MR&T System.** Use 2011 hydraulic flood data and associated MR&T component performance to evaluate the need for an updated flow line study for the System. Physical and hydraulic changes in the river system and complex flow patterns at Morganza, Bonnet Carre, and the Old River Control Complex should be examined to determine if a change in flow line data or water control plans is warranted.
- **Coordinate a regional "triage" effort to prioritize, refine and implement the recommendations identified in the MR&T System Post Flood Report.** The next steps in advancing the preliminary MR&T recommendations in this report will utilize the existing regional program management structure and process to further screen, combine, prioritize, refine, and develop detailed scopes for recommendation implementation. This process is vitally important due to the need to establish coordinated MR&T improvement, regional priorities, and because there is limited funding available to accomplish these tasks.

Many of the recommendations developed through this effort are considered preliminary and have not yet been fully scoped or vetted. The next steps in their advancement will include further screening, regional prioritization, refinement, detailed scoping, and analysis. Some of the recommendations provided are already moving forward (e.g., BPNM operation assessment, examination of river flow changes, etc.) and will continue to be advanced. The process of implementing the PFR recommendations will result in improved performance of the MR&T System and further reduce flood risks within the Lower Mississippi River Valley.

MISSISSIPPI RIVER AND TRIBUTARIES SYSTEM

2011 POST-FLOOD REPORT

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AAR - After Action Reports
ABLD - Atchafalaya Basin Levee District
ACE-IT - Army Corps of Engineers-Information Technology
ACM - Articulated Concrete Mattress
ADCP - Acoustic Doppler Current Profiler
AHP - Above Head of Passes
ALD - Algiers Levee District
AOR - Area of Responsibility
BCDS - Bayou Courtableau Drainage Structure
BDDS - Bayou Darbonne Drainage Structure
BEL - Brunswick Extension Levee
BLHF - Bottomland Hardwood Forests
BPNM - Birds Point-New Madrid
CFS - Cubic Feet Per Second
CI – Channel Improvement
CMT - Change Management Team
CoP - Community of Practice
CORPS - US Army Corps of Engineers
CSP - Concrete Slope Paving
CY - Cubic Yards
DAR - Damage Assessment Report
DD - Drainage District
DOP - Degree of Protection
DQC - District Quality Control
EBMRL - East Bank Mississippi River Levee
EOC - Emergency Operations Center
EP - Engineering Pamphlet
ER - Engineering Regulation
ERDC - Engineer Research and Development Center
FCA - Flood Control Act
FCCE - Flood Control and Coastal Emergencies
FEMA – Federal Emergency Management Agency
FESM - Flood Event Simulation Model
FREEBOARD - Field Reconnaissance Emergency Equipment Brokering Operational Assignment Regional Defense
FRAGO – Fragmentation Order
FRM - Flood Risk Management
FRMS - Flood Risk Management System
FRR - Flood Risk Reduction
GIWW - Gulf Intracoastal Waterway
HAZUS – Hazards – United States (FEMA Software Program)

HEC-FIA - Hydrologic Engineering Center's Flood Impact Analysis
HEC-RAS - Hydrologic Engineering Center's River Analysis System
HQUSACE - Headquarters , US Army Corps of Engineers
Hz - Hertz
I/O - Inflow/Outflow
IHNC – Inner Harbor Navigation Canal
IRTF - Interagency Recovery Task Force
LDB – Left Descending Bank
LDWF - Louisiana Department of Wildlife Fisheries
LMR - Lower Mississippi River
LMRV - Lower Mississippi River Valley
LRD - Great Lakes and Ohio River Division
LRL - Louisville, Kentucky District
LRN - Nashville, Tennessee District
M/V - Motor Vessel
MAF – Million Acre Feet
MDWFP - Mississippi Department of Wildlife, Fisheries and Parks
MICA - Mobile Information Collection Application
MR&T - Mississippi River and Tributaries
MRC - Mississippi River Commission
MRL - Mississippi River Levee
MSA - Metropolitan Statistical Areas
MVD - Mississippi Valley Division
MVK - Vicksburg, Mississippi District
MVM - Memphis, Tennessee District
MVN - New Orleans, Louisiana District
MVR - Rock Island, Illinois District
MVP – St. Paul, Minneapolis District
MVS - St. Louis, Missouri District
MVS-MCX – St. Louis District Mandatory Center of Expertise for Curation
NAGPRA - Native American Graves Protection and Repatriation Act
NASS CDL - National Agricultural Statistics Service Cropland Data Layer
NAVD88 – North American Vertical Datum of 1988
NGVD29 - National Geodetic Vertical Datum of 1929
NWD – Northwest Division
NWS – National Weather Service
O&M – Operation and Maintenance
ORCC – Old River Control Complex
ORL – Old River Lock
OWR – Operation Water - Recovery
PCDS – Point Coupee Drainage Structure
PCI – Per Capita Income
PCPS – Point Coupee Pumping Station
PDF – Project Design Flood
PFR – Post-Flood Report
PM – Program Manager
PPH – Persons Per Household
RDB – Right Descending Bank
RFC – River Forecast Center

RM – River Mile
SCL – Stability Control Line
SHPO – State Historic Preservation Office
SJBGS **–** St. John's Bayou Gravity Structure
SMLD **–** St. Mary Parish Levee District
SOP – Standard Operating Procedure
STRATCOMM – Strategic Communication
SWE – Snow Water Equivalent
SWL – Little Rock, Arkansas District
T&E – Threatened and/or Endangered
TEMA – Tennessee Emergency Management Agency
TVA **-** Tennessee Valley Authority
USCG – US Coast Guard
USGS – US Geological Survey
YBWL –Yazoo Backwater Levee District

SECTION I
INTRODUCTION

A. AUTHORITY AND GUIDANCE

The 2011 Mississippi River and Tributaries (MR&T) System Post-Flood Report (PFR) has been prepared in accordance with Engineering Regulation (ER) 1110-2-240 *Water Control Management* and ER 500-1-1 *Civil Emergency Management Program*. It presents the results of a comprehensive internal evaluation of the performance and operation of the MR&T flood risk management (FRM) system during the 2011 Flood. The US Army Corps of Engineers (Corps) Headquarters (HQ) and the Mississippi Valley Division (MVD) provided additional guidance and oversight. Where practical, this effort endeavored to support similar efforts being performed in response to flood events in Northwest Division, Great Lakes and Ohio River Division (LRD) and Southwestern Division (SWD) during 2011as well as the OPORD 2011-50 Greater Mississippi Basin System Performance Assessment being conducted by HQUSACE .

B. PURPOSE

This PFR was prepared in response to the historic flooding within an extensive portion of the Mississippi River basin in 2011. The 2011 Flood tested the MR&T flood risk management system (FRMS) like no flood before. Stage and flow rates broke records at several locations, and for the first time, three floodways—Birds Point-New Madrid (BPNM) Floodway, the Morganza Floodway, and the Bonnet Carré Spillway—were operated during a single flood event to relieve the enormous and sustained stress on the levee system. Rare and extreme events such as the 2011 Flood can cause significant damage and hardship. However, they also present a unique opportunity to learn about the function, capability, and reliability of FRM systems, and the knowledge and science that guide pre-flood planning, operational decision-making processes and post-event recovery operations. The PFR effort was designed and conducted to capitalize on that opportunity.

The purposes of the overall PFR effort were to: 1) evaluate and document the performance of the MR&T System and how it was managed to reduce flood risks during the 2011 Flood; 2) develop a system-wide approach to sequencing repair efforts to effectively address risks and repair the system to pre-flood conditions; and 3) identify and recommend opportunities to improve the System's future performance.

This PFR has been produced to document information useful for future system management decisions, operations, and improvements, and to serve as a useful reference for future FRM efforts elsewhere. It describes the important preparation and response actions taken and the processes utilized before, during, and after the 2011 Flood. It also provides the contextual information needed to understand how the entire MR&T System was used to mitigate risks, how it performed during the 2011 Flood, and what is needed to prepare the system for future flood events. Although the report provides recommendations, it is not a decision or implementation document. Where a decision document would be needed to implement recommendations, studies to fully evaluate proposed changes and potential improvements will be required.

C. SCOPE

The PFR effort utilized existing information to assess the operation and performance of the system and identify opportunities for improvements. Recommendations for improvements and future studies have been developed and documented to aid MR&T System recovery efforts and future system operation, management, and flood fight activities. Although the effort concentrates on the MR&T System, it incorporates information related to the operation of reservoirs associated with the Ohio, Arkansas, Mississippi, and Missouri Rivers that influenced flows within the MR&T system.

D. REPORT STRUCTURE

This report is structured to present information related to the MR&T System and the 2011 Flood in a format that meets the needs of a broad range of readers and future uses. Information is presented from both the individual component and system-based perspectives to allow readers to understand how each part of the system performed and was operated during the 2011 Flood and how it contributed to overall MR&T System performance. The main report provides the general information needed to understand the MR&T System and its operation and performance during the 2011 Flood and the post-flood recovery efforts necessary to restore and improve the system's capabilities. The supporting appendices contain detailed technical information to supplement the main report. The general content of each section is summarized as follows:

- **Section I** identifies the authorities and guidance applied to the effort and defines the intended purposes of the report and the technical and geographic scope of the evaluation effort.
- **Section II** provides the information needed to understand the MR&T System, its construction and operations and maintenance status and history, geographic extent, components, design capacity, and operational plan as well as the reasons it was constructed, the resources, and economies and infrastructure it protects.
- **Section III** characterizes the Flood and provides a summary of the meteorological conditions that contributed to the event. It also compares the Flood to other major floods to create the context for interpreting the analysis that is presented in subsequent sections.
- **Section IV** describes the response to the Flood, including pre-flood plans, emergency flood fight activities, operational decisions and communications/collaboration processes that were applied during the flood. It also describes the vulnerabilities in system components, plans, and processes that were revealed by the event.
- **Section V** describes the economic and environmental damages caused by the flood. It identifies the areas that were flooded and flood- related damages and economic damages prevented by the MR&T system and select components.
- **Section VI** describes and provides details on post-flood recovery activities related to the MR&T System. It summarizes damage inspection results including vulnerabilities of MR&T System components. It also summarizes a repair strategy that addresses the needs, prioritization, phasing, and sequencing efforts.
- **Section VII** summarizes the results of the MR&T System performance and operations assessment and the conclusions that can be made based on those results.
- **Section VIII** provides an overview of the creation of the Interagency Recovery Task Force (IRTF) and its participation in the recovery effort.
- **Section IX** presents overarching system recommendations and specific preliminary component team recommendations developed through the MR&T System assessment that should be considered to address potential vulnerabilities and improve structural and operational performance of the MR&T.
- **Plates** include detailed maps referenced in the report.
- **Appendices** provide additional details and technical information to support the analysis, conclusions and recommendations presented in the main report.

SECTION II

MISSISSIPPI RIVER & TRIBUTARIES PROJECT

A. MR&T SYSTEM INFORMATION

1. General MR&T Information. The MR&T Project is the largest FRMS in the world. It protects the 36,000-square-mile Lower Mississippi River Valley (LMRV) from periodic overflows of the Mississippi River. Figure II-1 shows the major river systems that comprise the Mississippi River drainage basin. The MR&T System is designed to convey the project design flood (PDF), represented by the maximum event that had a reasonable probability of occurring from a meteorological viewpoint.

Figure II-1. Major River Systems within the Mississippi River Basin

The MR&T System includes an extensive levee system; floodways to divert excess flows past critical reaches; channel improvement and stabilization features to protect the integrity of flood risk management measures and to ensure proper alignment and depth of the navigation channel; and a system of reservoirs to regulate flows and backwater areas to provide storage during extreme events. Additionally, there are tributary basin improvements including levees, headwater reservoirs, and pumping stations that expand FRM coverage and improve drainage into adjacent areas within the alluvial valley. The main stem levee system begins at the head of the alluvial valley at Cape Girardeau, MO, and continues to Venice, LA, near the Gulf of Mexico on the right descending bank and to Bohemia, LA on the left descending bank. Figure II-2 identifies and provides the general locations of the primary MR&T System components. The MR&T levee system includes 3,787 miles of authorized embankments and floodwalls. Of this, nearly 2,216 miles are along the main stem Mississippi River, and the remaining levees are backwater, tributary, and floodway levees.

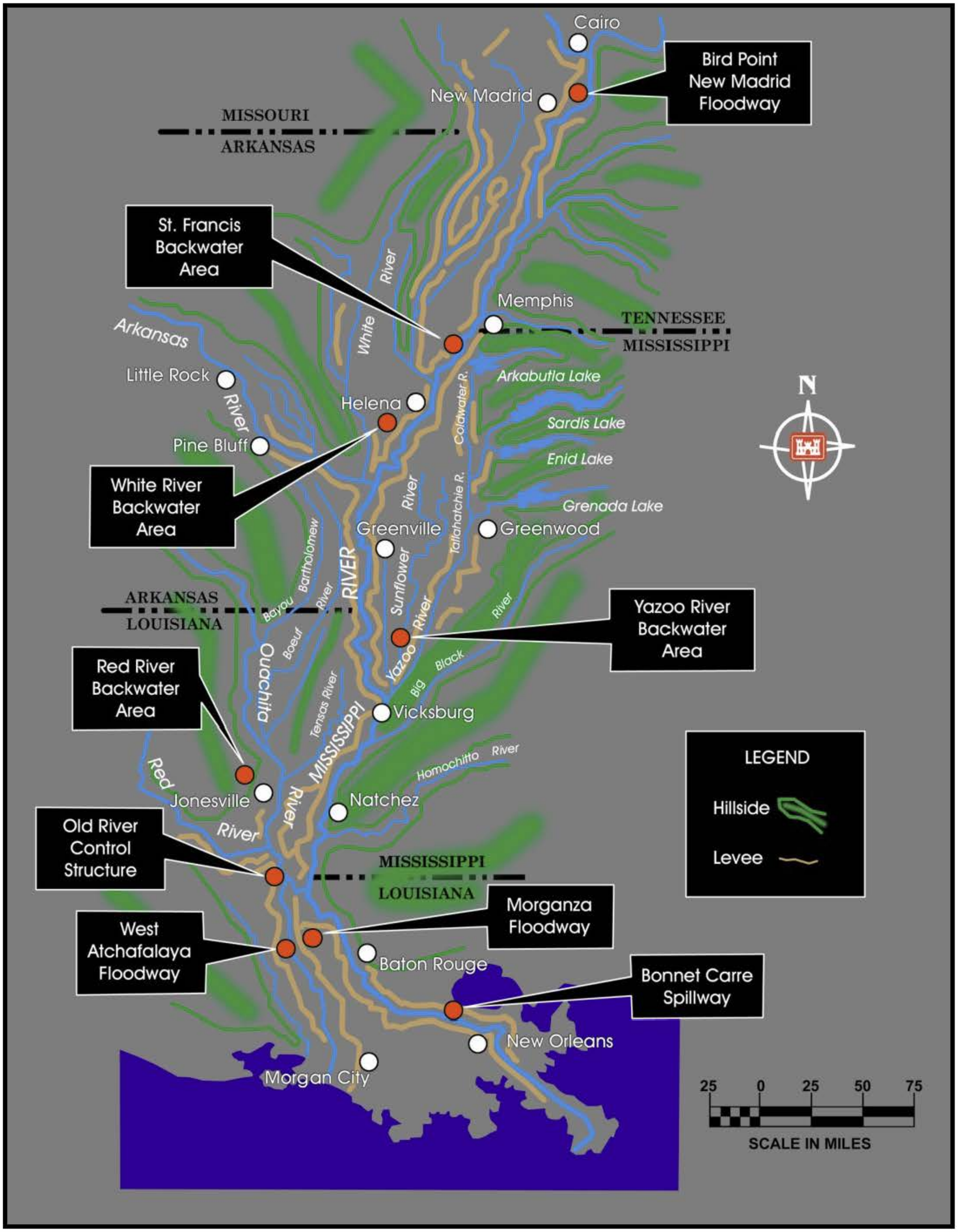


Figure II-2. General Locations of Primary Mississippi & Tributaries System Components

2. Physical Infrastructure and Operational Strategy. MR&T FRMS components consist of completed and uncompleted structures and improvements. The individual structures are operated as a system in accordance with the MR&T Flood Control Plan, to reduce overall flood risks throughout the LMRV. The design and operational strategy for the MR&T System does not attempt to entirely exclude the river from its natural floodplain. Instead, it accommodates the natural tendency of the river during extraordinary floods by incorporating floodway and backwater features that are not utilized during small and more frequent flood events.

Levees are the backbone of the MR&T Flood Control Plan. They protect the vast expanse of the developed alluvial valley from periodic overflows of the Mississippi River. The grade and section of the present levee system dwarf those of the system that was overwhelmed during the 1927 flood (figure II-3.) In addition to higher and wider levees, the MR&T levee designs incorporate technological advancements that account for the type, condition, and moisture content of material used in the construction of the levees. The design levee grades provide for freeboard – the distance between the PDF flow line and the top of the levee. The presently approved freeboard is 3 feet on the Mississippi River levees below Cairo, IL, to the Old River Control Complex (ORCC), 3 to 5 feet from the ORCC to Venice, LA, 3 feet on the Bonnet Carre guide levees and no freeboard to 2 feet of freeboard on the Atchafalaya Basin Floodway System levees. Levee grades between Cape Girardeau and Cairo and along the south banks of the Arkansas and Red rivers provide for a three-foot minimum freeboard over the maximum tributary flood meeting the maximum flood of record on the Mississippi River, with provisions to ensure that the same flood meeting the PDF will not overtop the levee.

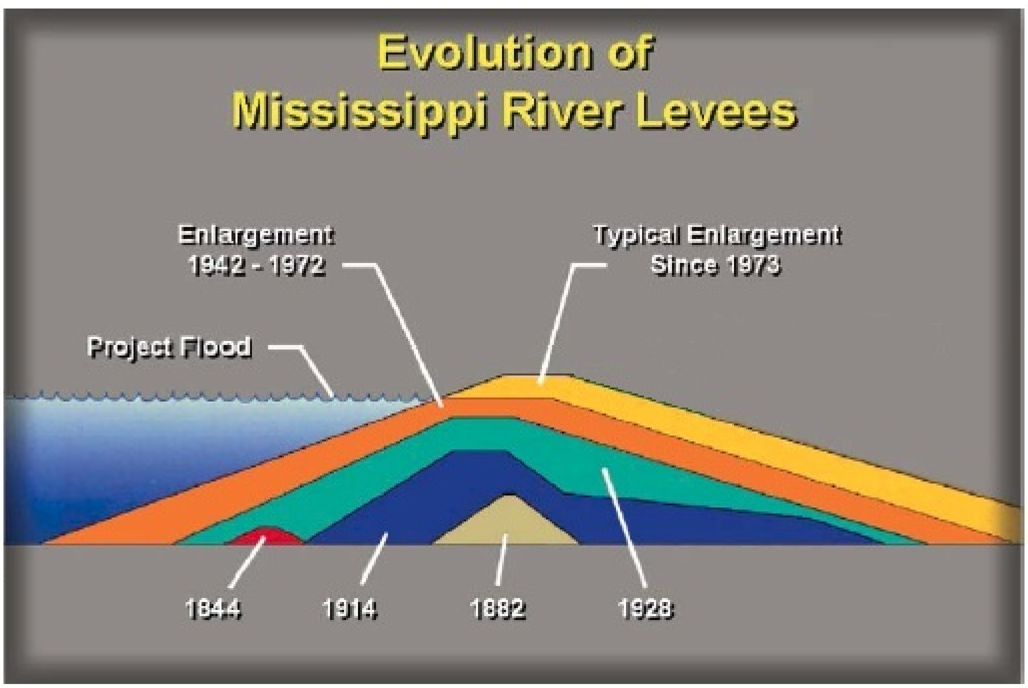


Figure II-3. Evolution of Mississippi River Levees (1844-Present)

The integrity of the levee system is also bolstered by advancements in the design, construction, installation and maintenance of seepage control measures, to include landside berms, drainage trenches, drainage blankets, and relief wells. Additionally, more than 1,000 miles of articulated concrete mattress revetment, over 300 miles of dikes and numerous hard points, chevrons and bendway weirs associated with channel improvement efforts maintain a stable channel protecting the levees from erosion and assuring the reliability of the navigation channel.

At critical stages or flow rates, other features are activated to control and convey floodwaters and relieve stress on the levees. The first key feature is in the vicinity of Cairo, IL. When the river reaches critical stages on the Cairo gage, the BPNM floodway is operated to divert up to about 550,000 cfs and prevent flood stages from exceeding the design elevation of the levees and floodways at and near Cairo, IL, the levees along the west bank above Birds Point, and the east bank levee adjacent to the floodway.

There are two major reservoirs—Kentucky and Barkley Lakes— on the Tennessee and Cumberland rivers that are not features of the MR&T project, but are authorized to reduce flood stages on the Mississippi River in the vicinity of and downriver from Cairo. Because of the close proximity of the reservoirs to the confluence of the Mississippi and Ohio rivers, regulation of the reservoirs has a predictable influence on the operation of the BPNM floodway. The 1944 FCA directs the Tennessee Valley Authority (TVA) to regulate the release of water from the Tennessee River into the Ohio River in accordance with instructions from the Corps. Objectives developed by the Great Lakes and Ohio River Division (LRD) for the Kentucky-Barkley reservoir outflows have priorities to safeguard the Mississippi River levee system, to reduce the frequency of use of the BPNM floodway and to reduce the frequency and magnitude of flooding of lands along the lower Ohio and Mississippi rivers which are unprotected by levees. When floods threaten the flood control features along the upper reaches of the MR&T project, the MRC president and the LRD commander—a position that also serves as a member of the Mississippi River Commission—work together to regulate releases from Barkley and Kentucky lakes with the concurrence of the general manager of the TVA to accomplish these objectives.

Between the lower end of the BPNM floodway and the Red River, a combination of flood control reservoirs, backwater areas and a comprehensive channel improvement and rectification programs supplement the levee system in passing floods. Backwater areas are located at the mouths of the St. Francis, White, Yazoo, and Red Rivers. Significant portions of the upper sections of these backwater areas receive protection from overflows of the Mississippi River afforded by the mainline levees. The lower portions of these areas serve as natural storage during larger floods. The backwater levees are designed to naturally overtop when flood stages along the main stem of the Mississippi River reach specified levels. When flood stages subside, floodwaters within the backwater areas drain through floodgates or is pumped. The channel rectification program improves the carrying capacity of the main channel and lowers the flood flow line through the use of cutoffs (severing large bends from the river) and corrective dredging.

From the Red River backwater to the Gulf of Mexico, the MR&T flood control plan uses a more elaborate system to manipulate flood waters. The first key component of that reach is the ORCC. Construction of the ORCC began in 1954 to prevent the Atchafalaya from capturing the Mississippi River. The complex is designed to maintain the 1950 latitude flow distribution between the Mississippi River and the Atchafalaya/Red River System of 70 percent to 30 percent, respectively.

Approximately 30 miles downstream from the ORCC, the Morganza Floodway provides for additional diversion of floodwaters. Governed by a 3,900-foot long and a 125-bay intake structure, the floodway can divert up to 600,000 cfs from the Mississippi River to the Atchafalaya basin when the Mississippi River flows below Red River Landing are projected to exceed 1,500,000 cfs.

The West Atchafalaya floodway extends along the west side of the Atchafalaya River Basin. The floodway contains an eight-mile long fuseplug section of levee at its head. When the fuseplug section crevasses or when the west bank Atchafalaya River levee overtops, the floodway can divert up to 250,000 cfs. Under the present water control plan, the West Atchafalaya Floodway would be the last feature of the flood control system to be used. The Atchafalaya River, the Morganza floodway, and the West Atchafalaya floodway converge at the lower end of the Atchafalaya River levees to form the Atchafalaya basin floodway. This floodway receives flow from the Red River and from the Mississippi River via the ORCC and the Morganza Floodway; it is designed to carry 1,500,000 cfs, the combined flow of the West Atchafalaya Floodway, Atchafalaya River, and Morganza Floodway. The Atchafalaya Basin Floodway has two outlets, Lower Atchafalaya River, with a project flood flow of 919,000 cfs, and Wax Lake Outlet, with a project flood flow of 581,000 cfs. The Avoca Island levee and Levees West of Berwick provide measures of risk reduction below Morgan City to communities such as Franklin, Calumet, and Patterson.

The MR&T Flood Control Plan provides additional control of the system below the Morganza floodway through the Bonnet Carré spillway, located approximately thirty miles above New Orleans, LA. The 7,200-foot long spillway structure is governed by 350 intake bays and connects to a six-mile long floodway that empties into Lake Pontchartrain. The floodway is designed to divert up to 250,000 cfs from the Mississippi River, to ensure the peak discharge flow at New Orleans does not exceed 1,250,000 cfs.

3. MR&T Project Design Flood. The PDF used for the original design of the MR&T Project, following the 1928 FCA authorization, was a combination of separate analyses conducted by the US Weather Bureau (now the National Weather Service) and the MRC. The discharges and flood stages developed by the agencies were very similar, but because the Weather Bureau analyzed the "maximum possible" flood in comparison to the Commission's analysis of the "maximum probable" flood, differences in the estimates emerged. Where such differences did occur, the higher stage was used in putting together the final PDF design.

The PDF has been re-evaluated and/or revised several times. Development of the current PDF began in 1954, when the Senate Committee on Public Works requested another thorough examination of all components of the MR&T Project. Pursuant to that request, the MRC and the Weather Bureau again conducted a cooperative study. This study incorporated previously unavailable data regarding the sequence, severity and distribution of past major storms and investigated 35 different hypothetical combinations of actual storms that produced significant amounts of precipitation and runoff. The Weather Bureau arranged the historical storms sequentially to mimic frontal movements and atmospheric situations that were consistent with those occurring naturally to determine the most feasible pattern capable of producing the greatest amount of runoff on the LMR. This included the consideration of storm transpositions, storm intensity adjustments, seasonal variations, and storm mechanics. In simpler terms, the Weather Bureau developed the project design storm series from various combinations of storms and resultant floods— referred to as hypo floods— represented by the maximum event that had a reasonable probability of occurring from a meteorological viewpoint.

The studies revealed that Hypo-Flood 58A had the most probable chance of producing the greatest discharge on the LMR from Cairo to the Gulf of Mexico. Three severe storms comprised Hypo-Flood 58A. The first storm is the 1937 storm that struck the Ohio and LMR basins, with runoff increased by 10 percent. It is followed 3 days later by the 1950 storm over the same general area. This storm is followed 3 days later by the 1938 storm, with its center transposed 90 miles to the north and the rainfall pattern rotated by 20 degrees to maximize its coverage over all the tributary basins on the lower Mississippi River.

To convert Hypo-Flood 58A into the PDF, the MRC developed the flood flows that would occur from the three storms and routed them through the tributary systems under three conditions: unregulated by reservoirs; regulated by reservoirs that existed in 1950; and regulated by the reservoirs that existed at that time, plus those proposed to be constructed in the near future (1960 timeframe). The flood flows were then routed down the Mississippi River to determine the peak discharges at key locations. The MRC selected the 58A flood with near future reservoirs condition, referred to as 58A-EN (existing or near completion), as the basis for the PDF flowline and adopted it as the PDF in 1956. See Appendix A for a list of the "future reservoirs".

Following the 1973 flood, the MRC once again reviewed the adequacy of the PDF. The review concluded that the thorough approach used in 1955 was based on sound technology that remained reliable by current standards. The PDF discharges developed in 1955 have remained unchanged to present day except for the distribution of PDF flows through the lower Atchafalaya and Wax Lake outlets in the Atchafalaya Basin. The distribution of these two flows has changed over time as documented in the Atchafalaya Flowline Report in 2010. Figure II-4 provides a simplified illustration of the current PDF.

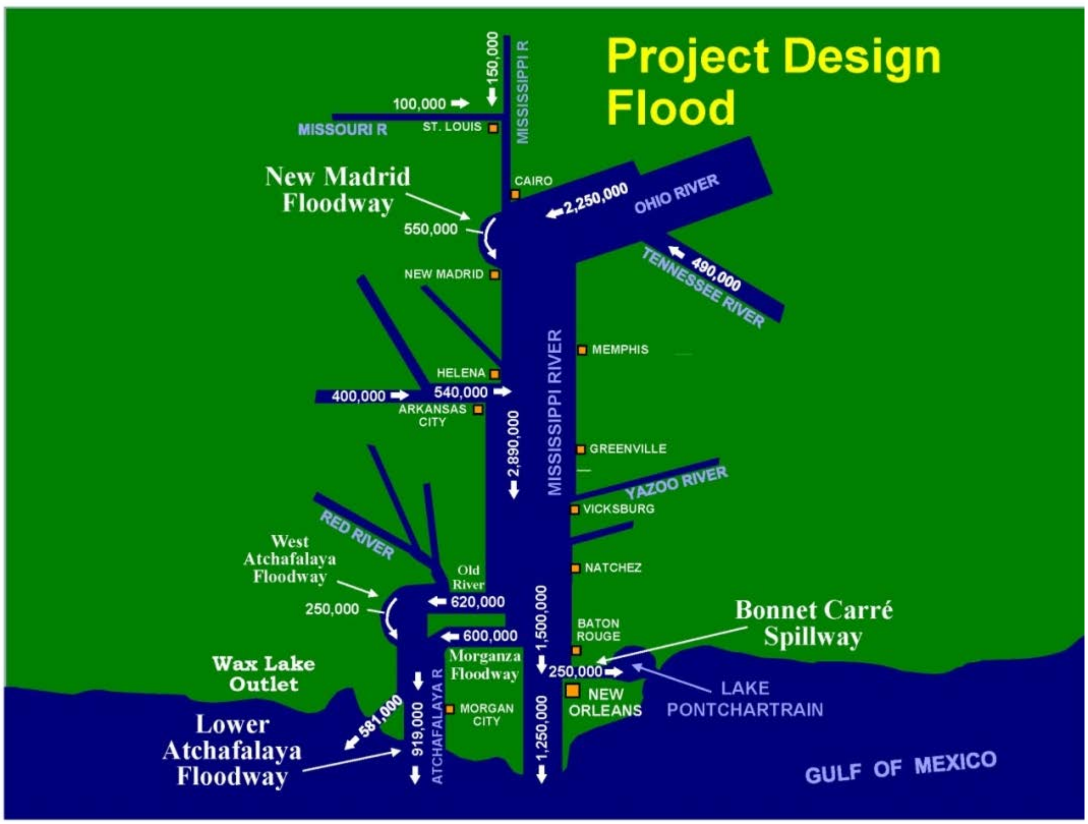


Figure II-4. Current Project Design Flood Diagram

B. MR&T BACKGROUND

1. Geology. The LMR lies within the Central Gulf Coastal Plain physiographic province. A northward extending lobe, the Mississippi Embayment of this province follows the axis of the Mississippi Basin and comprises the northern part of the LMRV (Schumm et al. 1982). Virtually all LMRV landforms and deposits are the result of fluvial, eolian, or marine processes.

The LMRV varies in width between 40 and 110 miles and includes parts of Missouri, Illinois, Tennessee, Kentucky, Arkansas, Mississippi, and Louisiana. The topography of the 53,000 square mile LMRV is characterized by a flat to slightly undulating surface underlain by alluvial and terrace deposits. Average floodplain elevations in the LMRV decline from about 325 feet mean sea level (msl) in extreme southern Illinois to about 40 feet msl at the northern edge of the deltaic plain. The average down valley slope is only 0.6 feet/mile. Average relief in the upper part of the LMRV is about 25 feet and declines progressively southward. Uplands bordering the LMRV typically attain elevations of about 200 feet above those of the adjacent floodplain. Upland elevations also steadily decline southward.

Soils in the LMRV range up to 300 feet in depth and consist mainly of sands and silt, grading progressively to very fine sands and silts in the lower portion of the area with extensive deposits of clay scattered through these formations. Typical of streams flowing through alluvial valleys, the LMR developed a highly sinuous course, creating numerous meander loops, bends, and oxbow lakes. Historically, the river shifted its channel frequently and reworked parts of its alluvial meander belt, thus contributing to the complexity of the soils structure and hydrology of the area (Saucier 1994).

One distinct feature of the LMRV is the formation of natural levees along the banks of rivers and the associated backwater deposits dominated by dense alluvial clays that historically supported extensive wetland areas. The banks of the river can be as much as 10 to 15 feet higher than the lowlands farther back from the river. Because of these natural levees, drainage within the floodplain, frequently flows away from the Mississippi River to lower elevations near the valley walls, except near tributary confluences. Bottomland drainage is provided by streams running parallel to the river and joining it through major tributaries or at points where the river meandered close to the valley wall. The clays that formed these features have low permeability and limit the ability of rainwater to infiltrate the ground surface (Kleiss et al. 2000).

2. Flood-Related History. French settlers began constructing the first levee on the Mississippi River in 1717 to protect the fledgling City of New Orleans from high water. That original levee was only 3 feet high and 5,400 feet long. The French, and later the Spanish, extended the modest levee system up the river, but progress was slow with the bulk of the work left to the landowners along the river. By 1802, the levees extended as far north as Baton Rouge; by 1849, they had almost reached the mouth of the Arkansas River along the west bank. Each landowner built his section of levee according to his own design and capability. In 1850, the Swamp Lands Act transferred low lying lands to the states, the sale of which allowed the states to fund levee construction. Levee boards were set up in the various counties along the river, and the Corps of Engineers provided technical guidance. The Civil War interrupted all progress on the levees and navigation improvements along the LMR.

Ongoing flooding and navigation issues led to the creation of the MRC in 1879. Public opinion at that time was opposed to Federal intervention for protection of private property in times of flood. Between 1879 and 1917 appropriations for flood control were publicly proclaimed to be for navigation, but progress on the levees continued. The floods varied in stage and duration and each one led to changes in how levees were constructed and provided impetus for more coordinated levee systems.

The FCA of 1917 appropriated $45 million with three provisions: 1) levees were authorized for the purpose of flood control; 2) local interests had to contribute 1/3 of the cost of levee construction; and 3) the MRC was authorized to use funds on the tributary streams to protect the Upper Mississippi River Basin from flooding. Work continued on the levee system and in 1926 the MRC believed "the day when the Lower Mississippi Valley would be safe from the ravages of floods was within sight."

The most important historical flood, with respect to the MR&T System, was the Flood of 1927. The Flood of 1927 began with heavy rains that pounded the central basin of the Mississippi in the summer of 1926. By September, swollen tributaries were pouring through Kansas and Iowa. From December 1926 to April 1927, heavy rains continued throughout the central areas of the basin. There were three flood waves on the lower Mississippi in January, February and April, increasing in magnitude each time. In February, the White and Little Red Rivers broke through the levees in Arkansas, flooding more than 100,000 acres with 10 to 15 feet of water. 5,000 people were left homeless.

The April rains were very intense and river stages rose rapidly. By April 9, more than one million acres of land were flooded, and the rain continued to fall. On April 19, a levee near New Madrid, MO, burst, flooding an additional one million acres. Portions of seven states (Missouri, Illinois, Kentucky, Tennessee Arkansas, Louisiana, and Mississippi) were under water.

At Mounds Landing near Greenville, MS, a flood surge blew out another levee. Swirling eastward, the flood ravaged 2.7 million acres of farmland before rejoining the mainstem of the Mississippi at Vicksburg, MS. The levee break at Mounds Landing was the greatest single crevasse ever to occur on the Mississippi River. It flooded an area 50 miles wide and 100 miles long with up to 20 feet of water. It put water over the tops of houses 75 miles away. There were numerous breaks in the levees on the west bank of the river, also, inundating lands as far west as Monroe, LA. The flood continued south and west toward the City of Melville and the fast-running Atchafalaya River. It swept through town leaving much of it severely damaged.

By August 1927, when the flood finally subsided, the disaster had displaced about 700,000 people. It is not known exactly how many died in the great disaster. Historians once estimated the death toll at 250 victims, but deaths due to disease and exposure after the immediate flood are hard to tally; some estimates exceed 1,000 deaths. Twenty-six thousand square miles were inundated to depths up to 30 feet, levees were crevassed, and cities, towns and farms lay waste. Crops were destroyed and industries and transportation paralyzed.

At a time when the Federal budget barely exceeded $3 billion, the flood, directly and indirectly, caused an estimated $1 billion in property damage. It was a disaster of tremendous proportion, awakening the national conscience to the need for a comprehensive program to reduce flood risks within the LMR. The 1927 flood also illustrated that the “levees only” approach was inadequate to control and safely handle the river’s flood flows. Chief Engineer General Edgar Jadwin’s plan differed from the "levees only" approach in three major respects: 1.) the incorporation of floodways to divert peak flows and hold down stages in the main channel; 2.) backwater areas to divert peak flows from the river and store a portion of the flood waters near the peak of the flood resulting in reduced downstream stages; and 3.) designing all works on the basis of a PDF -- a great hypothetical flood derived from examining historic rainfall and runoff patterns.

This initial system of works was formalized in the 1928 FCA, which authorized the Jadwin Plan, or what came to be known as the Mississippi River and Tributaries Project. The features of the plan provided for higher and stronger levees, set back from the main channel where feasible. To avoid significant increases in levee heights, the plan provided for five floodways—the BPNM, Boeuf, Bonnet Carré, and East and West Atchafalaya floodways (note: Boeuf was later substituted by Morganza)—to safely divert excess waters past critical reaches in the levee system to prevent flows from exceeding MR&T levee design elevations. The plan also provided the revetment of caving banks and channel stabilization features to improve navigation.

The 1929 flood tested the new levees. For the first time, all of the mainline levees held.

The Great Flood of 1937 along the Ohio and lower Mississippi River Valleys provided the first test of the entire MR&T flood control project and, more precisely, of the BPNM Floodway. The flood was caused by flow from the Ohio River. Although the Mississippi River above Cairo, IL was at a low stage, the combined flows of the Ohio and Mississippi Rivers surpassed the highest flood stages ever experienced between Cairo and Helena, AR. On January 24 and 25, 1937, the BPNM Floodway was artificially crevassed. At crest stage, the MRC estimated that the Floodway was passing approximately one-fourth of the entire flood discharge at Cairo. If the floodway had not been artificially crevassed, most of the Floodway would still have been flooded as a result of natural crevasses and overtopping along the frontline levee. Major floods along the Lower Mississippi River followed in 1945, 1950, 1973, 1975, 1979, 1983, 1997 and 2008. The Bonnet Carré Spillway was operated for each of these floods, but the Morganza Floodway was operated only in 1973.

The PDF flows are greater in magnitude than those of both the 2011 and 1927 floods from Cairo, IL to Red River Landing. At Cairo, IL, the PDF is estimated at 2,360,000 cfs. The 1927 Flood was about 91% of the PDF at the mouth of the Arkansas River and about 76% of the PDF at the latitude of Red River Landing, amounting to 3,030,000 cfs at the latter location about 60 miles below Natchez, MS. Based on stage and flow rates, the 2011 Flood was approximately 85 percent of the PDF through large portions of the MR&T System. It is worth noting that the MR&T System was approximately 89% complete during the 2011 Flood. Thus, it likely could not pass the PDF prior to nor after the 2011 Flood (until it is completed).

Figure II-5 displays a comparison of the inundation extents of the 1927 and 2011 Floods.

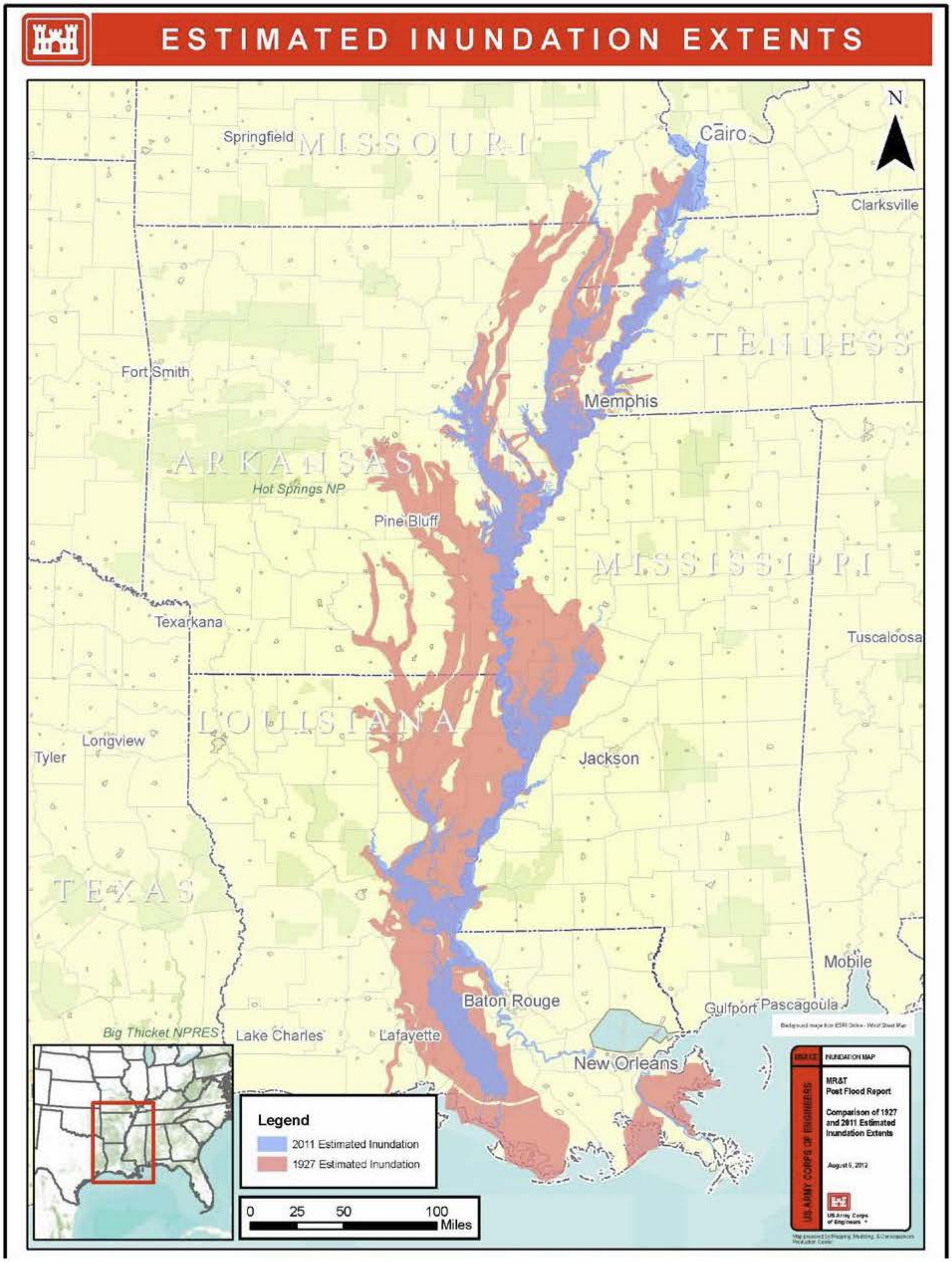


Figure II-5. Inundation Comparison: 1927 Flood vs. 2011 Flood

3. MR&T Project Status. Since 1928, the Federal Government has invested approximately $13.9 billion in the MR&T Project. In 2008, it was estimated that $500 million was needed annually to permit efficient completion of programmed construction and operation and maintenance. Prior to 2011, the MR&T received one-third to one-half of its funding through Congressional adds. In 2008, which was typical of this era, the total Project allocation was $387,402,000, broken down as:

- $196,601,000 (50.7%) - construction (re-evaluation studies, PED, & construction)
- $181,700,000 (47%) - maintenance
- $9,101,000 (2.3%) - planning

Prior to the 2011 Flood, the MR&T System was approximately 89 percent physically complete with a remaining balance-to-complete cost of approximately $3 billion and an estimated date of completion of 2031. The priorities for the known deficiencies change over time are tracked and regularly reassessed in Master Plans for the Mississippi River Levee System and Channel Improvements Program.

Prior to the flood, some reaches of the mainline Mississippi River Levees could not safely convey the PDF, and other reaches were in need of work to prevent failures due to seepage or deficient cross sections. Additionally, channel improvements were needed to assure that alignment of the Mississippi River remained stable to provide a dependable navigation channel and to prevent the meander of the river from destroying MR&T System features.

Detailed information related to the incomplete portions of the levee system is provided in Appendix B. It is worth noting in this report that many of the deficiencies that were identified as high priorities prior to the 2011 Flood are associated with significant flood fight issues and damages that are discussed in subsequent sections of this report. Many of these pre-existing deficiencies were identified as high priorities prior to the 2011 flood. Some had designs underway to repair the deficiency and construct as funding allowed. The magnitude of this flood further deteriorated the conditions, expanded the scope of the deficiency, and/or revealed unacceptable vulnerabilities thus elevating the need for repairs and supplemental funding to expedite construction.

4. Environmental Conditions. The LMRV extends from its northern extent at Cape Girardeau, MO to its southern delta and covers 36,000 square miles of diverse forest, grasslands, swamps, and marshes. The LMRV includes the Atchafalaya, Red, Yazoo, Arkansas, White, and St. Francis River Basins, and the Mississippi River Delta plain sub-regions. Each of these has its own unique physiographic character and wildlife community. The LMR is typically defined as the stretch of the river downstream of its confluence with the Ohio River.

a. Terrestrial Resources

i. Land Resources. The LMR leveed floodplain, which includes the floodplain contained between the levees (i.e., the batture) and backwater areas, is a dynamic freshwater ecosystem, often changing markedly in response to the river's annual hydrologic regime. The 2.8 million-acre leveed floodplain (area between the levees) is interspersed with abandoned channels, meander scars, and large expanses of forested wetlands. These areas provide a diverse array of aquatic habitat types and are connected to the river at high water. Table II-1 displays the distribution of primary environments within the floodplain areas.

Table II-1. Distribution of Environments Within the LMRV

Environment	Area (acres) (% total)
Bottom land hardwood forests	981,887 (35 %)
Agricultural Lands	478,345 (17 %)
Open Water	515,656 (18 %)
Backwater Areas	680,800 (24 %)
Other	137,186 (6 %)
Total	**2,793, 874**

Bottom land hardwood forests (BLHF) fill an important ecologic niche in the southern United States, and area valuable source of many natural resources (e.g., timber, recreation) and as the primary habitat for a wide range of organisms. While BLHF make up a sizeable fraction of the leveed floodplain, agriculture and timber harvesting have drastically diminished their national distribution since the time of first European-settlement. The construction of various levee systems, drainage efforts, channelization, and land clearing has altered the natural patterns of surface water drainage within the region, which has affected the distribution of ecosystems, such as BLHF, by increasing water availability in some regions and decreasing it in others. Table II-2 offers some examples of the wealth of flora currently found in BLHFs as well as in backwater wetland areas of the LMR region.

Table II-2. Vegetation Typically Found in Various Environments of the LMRV

Environment	Typical Trees	Typical Understory
BLHF	water oak (*Quercus nigra*); Nuttall oak (*Q.nuttallii*); cherrybark oak (*Q.falcata*); native pecan (*Carya illinoensis*); red maple (*Acer rubrum* var.*drummondii*); sweetgum (*Liquidambar styraciflua*); and eastern cottonwood (*Populus deltoides*).	palmetto (*Sabal minor*); greenbrier (*Smilax rotundifolia*); muscadine (*Vitis rotundifolia*); and poison ivy (*Toxicodendron radicans*).
Backwater Areas/ Wetlands	cypress (*Taxodium distichum*); water tupelo (*Nyssa aquatic*); water oak; green ash (*Fraxinus pennsylvanica*); red maple; and black willow (*Salix nigra*).	buttonbush (*Cephalanthus occidentalis*); lizardtail (*Saururus cernuus*); water hyacinth (*Eichhornia crassipes)*; sedges; and rushes.

The LMRV contains many different types of wetlands including those found within forested areas, river valley backwater areas, and around areas of open water. The Atchafalaya River Basin within the LMRV contains over a 500,000 acres of wetlands alone, making it the largest "river swamp" in North America. Over 40 percent of our Nation's coastal wetlands are found in Louisiana. Some of these coastal wetlands rely upon the Mississippi River for freshwater, sediments, and nutrients. Wetlands surrounding the Mississippi River are prime winter foraging grounds for many species of birds that rely heavily on the Mississippi flyway for migration. Approximately 70 percent of the Nation's migratory waterfowl travel through the Mississippi flyway annually. Unfortunately, much of the coastal wetlands within the Mississippi River delta region are decreasing in area (wetland loss rate of 16.57 mi^2 per year, trend analyses 1985 - 2010) due to land loss and submergence caused by both natural and anthropogenic subsidence and altered surface water hydrology.

ii. Wildlife Resource. The BLHF and coastal wetland ecosystems are extremely productive wildlife and fisheries habitat (table II-3). For example, 34 mammalian, 164 avian, 39 reptilian, and 20 amphibian species have been documented within the backwater wetlands near the junction of the Red, Atchafalaya, and the Mississippi Rivers. The activities relating to the abundant wildlife resources within the

LMR ecosystem, such as hunting and eco-tourism, are a significant source of revenue for the surrounding local economies.

Table II-3. Animals Typically Found in Various Environments of the LMRV

Environment	Typical Wildlife
BLHF	white-tailed deer, raccoon, woodpeckers, owls, various songbirds, rabbits, mice, wild turkey, and squirrel.
Agricultural Lands	cottontail rabbit, mourning dove, raccoon, coyote, and opossum.
Open Water	migratory, waterfowl, herons, egrets, and wood ducks
Backwater Areas/Wetlands	muskrat, nutria (invasive), swamp rabbit, mink, river otter, and beaver

Three threatened or endangered (T/E) animal species are found throughout the LMRV; the Louisiana black bear (*Ursus americanus luteolus*), the interior least tern (*Sterna antillarum*), and the pallid sturgeon (*Scaphirhynchus albus*). The endangered fat pocketbook mussel (*Potamilus capax*) is also found in the river. An additional 16 T/E species are also found along the Mississippi River delta plain, such as the piping plover (*Charadrius melodus*), West Indian manatee (*Trichechus manatus*), and five species of sea turtle (e.g., *Leatherback (Dermochelys coriacea*). The Louisiana black bear's habitat primarily includes the Tensas River basin, the upper Atchafalaya River Basin, and the coastal St. Mary and Iberia parishes in Louisiana. The bear favors large cypress and tupelo trees for winter denning, and there is an effort to protect areas where these trees are abundant. It is estimated that agricultural development along the Mississippi River has reduced the bear's natural geographic range by 80 percent. The interior least tern was listed as an endangered species in 1985, and while its range includes riverine areas throughout the interior United States, relatively large populations frequent the Mississippi River between Cape Girardeau, MO southward to Vicksburg, MS.

b. Aquatic Resources

i. Water Resources. The aquatic resources of the LMRV include the main stem of the Mississippi River, its tributaries and floodplain side-channels, and both natural and man-made surface water impoundments (e.g., floodplain pools, borrow pit ponds, oxbow lakes, reservoirs, and estuaries). The Mississippi River and its side channels compose the majority of the aquatic area of the region for most river discharges.

The aquatic health and water quality within many LMRV aquatic ecosystems have been degraded due to several anthropogenic causes including: 1) agricultural runoff containing pesticides (e.g., atrazine and metolachlor) and fertilizers; 2) river engineering for flood management and navigation (i.e., channelization, levee construction); 3) aquifer depletion (which lowers summer base-flows beyond acceptable limits for many aquatic organisms); and 4) altered fluvial sedimentation regimes (e.g., impounding sediment behind dams, increasing sediment yields due to deforestation). Additionally, coastal aquatic areas are affected by canal construction, oil and gas exploration, sediment diversion, sea level rise, subsidence, and storm damages.

Table II-4 displays median water quality values for the Mississippi measured near Vicksburg, MS. These values typically do not significantly vary in space for the lower river reaches. Nutrients, originating from agricultural fertilizer, are the primary driver of hypoxic conditions (when dissolved oxygen dips below 2 parts per million [or 2 mg/L]) observed in the Gulf of Mexico. Approximately 90 percent of the Mississippi River's nitrate load originates from non-point sources within its upper basin and the Ohio River valley. Recently observed hypoxia in Mississippi Sound and Gulf Coast waters east of the Mississippi River may be linked to operation of the Bonnet Carré Spillway in 2008 and 2011 (Gundersen et al., 2012). A water-quality monitoring program for both the Mississippi River (employing five permanent water-quality measuring stations) and Atchafalaya River (employing two permanent water-quality measuring stations) has been established by the US Geological Survey (USGS) NASQAN program. Louisiana currently permits approximately 300 industrial and municipal sites to discharge wastewater into the Mississippi River, while it is used as the primary source of municipal water supply for approximately 1.5 million people.

Table II-4. Median Water Quality Values for the Mississippi River at Vicksburg During the Spring/Summer Flood Season

Water Quality Metric	Value
Suspended Sediment	~170.0 mg/L [1]
Nitrogen	~2.2 mg/L
Phosphorus	~0.2 mg/L
Metolachlor & Atrazine	~1.0 mg/L

The LMRV aquatic ecosystems have been significantly impacted from the introduction of invasive species. Invasive species threaten the diversity and abundance of native species, the ecological stability of infested waters, and the commercial, agricultural, aqua-cultural, and recreational activities dependent on those ecosystems. Five species of Asian carp [grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molotrix*), bighead carp (*H. nobilis*), and black carp (*Mylopharyngodon piceus*)] have invaded much of the LMRV. Common carp have been present since the mid-1800s while the other species have invaded within the last three to four decades. All of these fish have degraded native fish and possibly mussel populations by increasing competition for their food sources and habitat. Silver carp also pose a safety concern to boaters due to their propensity for jumping out of the water in front of moving vessels. Zebra mussel (*Dreissena polymorpha)* infestations have the potential to cause ecological changes in the major rivers of the LMRV as observed in the upper Mississippi River region. Their rapid reproduction, coupled with their ability to consume large quantities of microscopic plants and animals, degrades their local aquatic food web and places valuable commercial and sport fisheries at risk. The LMRV is also presently home of a number of invasive aquatic plants, such as giant salvinia, purple loosestrife, Eurasian watermilfoil, water hyacinth, water lettuce, hydrilla, etc., that quickly establish themselves and often replace native plants.

The coastal estuaries surrounding the Mississippi River delta, which includes areas stretching from Lake Pontchartrain to the Mississippi Sound and west to the Barataria Basin, are an extremely productive and robust ecosystem. Nutrient-rich fresh water from inland rivers, including the Mississippi River, mix with the saline sea water, creating a diverse range of coastal habitats. These areas are highly prized for recreational and commercial fishing for such species as spotted seatrout, blue crab, brown shrimp, and oysters. Many of Louisiana's coastal bays and Gulf waters to the three-mile limit are listed as impaired (i.e., not supporting designated uses) due to causes ranging from mercury in fish tissue to low dissolved oxygen [Louisiana Department of Environmental Quality's s *2010 Water Quality Inventory: Integrated Report (305(b)/303(d)]*.

ii. Fisheries. The waters of the LMRV support over 150 species of freshwater fish. The diversity and abundance of aquatic wildlife typically increases southward with increasing proximity to the river estuary. The mainstem of the Mississippi River may contain over 100 species in a short reach, including minnow, darters, suckers, catfish, and sturgeon. The pallid sturgeon (*Scaphiryhnchus albus*) was federally listed as an endangered species in 1990 and has been observed above New Orleans on the main stem of the river. Gravel bars within the main river are vital spawning habitat for sturgeon and other species of concern, such as paddlefish. While large dike pools in the Mississippi River can support 1,000 pounds of fish per acre, slackwater areas like borrow pit ponds support up to 600 pounds per acre including uncommon and imperiled wetland species (e.g., pugnose minnow, taillight shiner, paddlefish and alligator gar). Spring floods provide necessary access between swift river water and slower-moving floodplain side-channels and ponds, which fish use for enhanced forage and spawning.

There is a range of native freshwater mussel species present within the LMRV; however, water quality issues and channel modifications have caused significant declines in freshwater mussel populations. Channel responses such as headcutting and knickpoint migration, caused the deterioration of several populations. The fat pocketbook mussel (*Potamilus capax*) was listed as an endangered species in 1976. After the species was listed, populations were located in the St. Francis River and Gilliam's Chute. In recent years, its range has expanded to include other backwater, clayey river channels in southern Arkansas and Mississippi.

The Mississippi River and Atchafalaya River estuaries produce a large fraction of our Nation's fisheries and are critical habitat for gulf coast oysters and other shellfish. The Mississippi River estuary and northern gulf coast are key commercial fishing ground for many salt-water species including bay anchovy *(Anchoa mitchilli)*, Atlantic croaker (*Micropogonias undulatus)*, gulf menhaden *(Brevoortia patronus)*, blue crab *(Callinectes sapidus)*, northern brown shrimp *(Farfantepenaeus aztecus)*, and white shrimp *(Litopenaeus setiferus)*.

5. Cultural Resources. The alluvial valley of the Mississippi River was one of the most densely populated areas of North America in prehistoric (pre-European contact) times. Consequently, there are thousands of archaeological sites ranging from post-glacial Paleo-Indian to late prehistoric Mississippian cultures. A unique cultural florescence, not found anywhere else, known as the Poverty Point culture also developed in the valley during the late Archaic period, approximately 3,000 thousand years ago. Hundreds of archaeological sites have been listed on the NRHP, and a far greater number have been determined eligible for the NRHP. In addition, the floodplain contains a rich historic archaeological record, including French and Spanish colonial sites, 19th century antebellum mansions associated with the mythic old South (e.g., Oak Alley Plantation), Civil War sites, sharecroppers farms, and a wide variety of 19^{th} and 20^{th} century historic buildings and sites that together form a unique and irreplaceable archaeological record. Remnants of more than 300 nineteenth century plantation sites have been recorded within the MVN alone.

To illustrate the LMRV's unique prehistoric archaeological heritage, it should be noted that around 1,000 A.D., larger, more complex mound sites were erected by late prehistoric Mississippian cultures. The flat-top earthen temple mounds within the large towns of these Mississippian peoples are still evident across the LMRV. In the lower valley, the Emerald Mound site, the second largest Mississippian mound (next to Monk's Mound at Cahokia) lies just north of Natchez and close to the present course of the Mississippi River.

During the early historic (colonial) period the Natchez, the Tunica, the Quapaw, the Choctaw and the Chickasaw constructed village sites in close proximity to the Mississippi River and its major tributaries. While some of these village sites have been preserved, many have been lost. Levee construction, erosion, and other land disturbances (e.g., the great New Madrid earthquake of 1811-1812) have destroyed many prehistoric and historic archaeological sites on the river side of the levee. During the 1830s, the Mississippi River and major tributaries like the Arkansas River served as the major transportation corridor for the forced removal of the Five Civilized Tribes after the Indian Removal Act of 1830.

Another major category of historic properties is the largely unknown number of 19th century steamboat wrecks, which occurred during the height of steamboat navigation on the Mississippi, described so vividly in Mark Twain's classic *Life on the Mississippi*. In 1988, record low-water levels provided the Arkansas Archaeological Survey with an opportunity to examine a sample of these shipwrecks when the Mississippi River fell to 10 feet below zero on the Memphis gauge and exposed four and a half acres of 19th century water craft remains on the riverbed near Memphis. The Survey's archaeological fieldwork received national media attention and wide publication in academic and popular journals. This high density of previously unknown shipwrecks in the Memphis area would probably be found at other large river towns (e.g., Vicksburg and Natchez, MS) in the Study area. However, most of these steamboat wrecks have never been formally recorded or evaluated for the NRHP. Systematic underwater surveys, using side-scan sonar and magnetometers, have yet to be done in the Mississippi River Valley and its major tributaries.

6. Social/Economic Background. A comprehensive overview of the overall area affected physically or economically by the MR&T Project on the surrounding region is presented in order to provide the context and basis needed to understand and determine flood-related impacts along the lower reaches of the Mississippi River from Cape Girardeau, MO, to the Head of Passes, LA. This synopsis includes a description of the economic base area and its historical significance to the general region; a background of the MR&T Project; and a discussion of other Mississippi River improvements and accomplishments. A special emphasis is given to significant impacts relevant to project implementation. This includes a discussion of project effects regarding the economy, flood damages prevented by the Project, and other related impacts or contributions from the Project.

a. Background. The MR&T Project is vital to overall FRM within the Lower Mississippi River. Because of its low-lying valleys, flooding on the LMR threatens cities, property, and crops along its banks. The mainline levees are also continuously being upgraded to correct deficiencies following major floods (e.g., 1973 and 2011). It is expected, that when all upgrades have been completed, this project will provide FRM to an estimated population of about 6.4 million people in 119 counties and parishes along the Mississippi River.

b. The Economic Base Area. The impacted area encompasses approximately 71,800 square miles of land area considered to be physically, socially, or economically impacted by the MR&T Project. This economic base area used to assess economic impacts of the MR&T was larger than the 36,000-square-mile LMRV because it included full census block areas which may extend beyond the boundaries of the LMRV. This base area extends roughly from Cairo, IL, to the Gulf of Mexico, includes portions of seven states—Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee—and five Corps Districts along the LMR and tributaries region—Little Rock, AR (SWL), , Memphis, TN (MVM), MVN, MVR, MVS, and MVK. Thus, to illustrate socioeconomic impacts to each entity, statistical data will be displayed by both state and District. Other damages and impacts associated with the 2011 Mississippi River flood in these areas are discussed in more detail in Section V.

i. Impacted Areas. The MR&T economic base area begins in the vicinity of the Mississippi River's confluence with the Ohio River. At this point, it includes portions of four states—Illinois, Kentucky, Missouri, and Tennessee. The northernmost portions of the economic base area impacted by flooding are located in the LRL and LRN Districts. Impact areas in the LRL include nearly 1,500 square miles of land within 5 counties while damages in the LRN have the potential to impact approximately 500 square miles in 2 counties. There are about 430 square miles in 2 counties within the MVS. There are also counties that overlap multiple Districts, but they are only counted once.

The portion within the MVM starts at Cape Girardeau and extends southerly along the Mississippi River to Memphis, TN. This segment contains approximately 20,200 square miles of land in 35 counties of 5 states—15 in Arkansas; 4 in Kentucky; 1 in Mississippi; 9 in Missouri; and 6 in Tennessee. To the west, the SWL has approximately 2,000 square miles of land in 3 counties that were subjected to impacts from the flood.

The portion within the MVK stretches from the MVM boundary southward to the Mississippi River's confluence with the Red River in Louisiana. With approximately 31,200 square miles of land area, it comprises about 38 percent of the economic base area. This segment comprises 49 counties and parishes in three states—11 counties in Arkansas, 16 parishes in Louisiana, and 22 counties in Mississippi.

The remaining portion, located in the MVN, accounts for the southernmost portion of the LMR region and the Atchafalaya River Basin. Situated entirely in the State of Louisiana, this section covers approximately 17,300 square miles of land in 29 parishes along the Mississippi River from the Red River to the Gulf. A list of counties/parishes by state and Corps District is provided in table II-5.

ii. Socio-economic Statistics. The objective of the socioeconomic study is to provide a framework from which to help identify and understand the impacts, problems, and needs in the affected areas of the 2011 Mississippi River flood.

There are 119 counties and parishes along the Mississippi River in seven states that impacted by Mississippi River flooding. Socioeconomic statistics for 2010 conditions are presented in table II-6 for each Corps District.

Table II-5. 2010 MR&T Economic Base Area By District, State, and County/Parish

LITTLE ROCK DISTRICT		
ARKANSAS		
Independence	Jackson	Randolph

MEMPHIS DISTRICT						
ARKANSAS		**KENTUCKY**	**MISSISSIPPI**	**MISSOURI**		**TENNESSEE**
Arkansas	Mississippi	Ballard	DeSoto	Butler	Wayne	Dyer
Clay	Monroe	Carlisle		Cape Girardeau		Lake
Craighead	Phillips	Fulton		Dunklin		Lauderdale
Crittenden	Poinsett	Hickman		Mississippi		Obion
Cross	St. Francis			New Madrid		Shelby
Greene	White			Pemiscot		Tipton
Lawrence	Woodruff			Scott		
Lee				Stoddard		

NEW ORLEANS DISTRICT					
LOUISIANA					
Acadia		Iberville	Orleans	St. James	Tangipahoa
Allen		Jefferson	Plaquemines	St. John the Baptist	Terrebonne
Ascension	East Baton Rouge		Pointe Coupee	St. Landry	Vermilion
Assumption	East Feliciana	Lafayette	Rapides	St. Martin	West Baton Rouge
Avoyelles	Evangeline	Lafourche	St. Bernard	St. Mary	West Feliciana
	Iberia	Livingston	St. Charles	St. Tammany	

ST. LOUIS DISTRICT			
ILLINOIS		**MISSOURI**	
Alexander	Pulaski	Perry	Bollinger

VICKSBURG DISTRICT								
ARKANSAS			**LOUISIANA**			**MISSISSIPPI**		
Ashley	Desha	Ouachita	Caldwell	La Salle	Tensas	Adams	Issaquena	Tate
Bradley	Drew	Prairie	Catahoula	Lincoln	Union	Bolivar	Jefferson	Tunica
Calhoun	Jefferson	Union	Concordia	Madison	West Carroll	Carroll	Leflore	Warren
Chicot	Lincoln		East Carroll	Morehouse	Winn	Claiborne	Panola	Washington
			Franklin	Ouachita		Coahoma	Quitman	Wilkinson
			Grant	Richland		Grenada	Sharkey	Yazoo
						Holmes	Sunflower	
						Humphreys	Tallahatchie	

Table II-6. 2010 Socioeconomic Statistics in the MR&T Area by Corps District [1]

Socioeconomic Category	SWL AR (3 counties)		MVM AR, KY, MO, MS, TN (35 counties)		MVN LA (31parishes)	MVS IL (3 counties)	MVK AR, LA, MS (47 counties)	Total (119)
Land Area (Square Miles)	2,050		20,219		17,295	437	31,162	71,163
Population Density (Persons Per Square Mile)	35.4		101.4		178.6	33.1	36.8	77.1
Total Population, 2010	72,613		2,049,355		3,089,524	14,339	1,148,230	6,374,061
Total Population, 2000	71,752		1,884,869		2,978,795	15,579	1,210,219	6,161,214
Change, 2000-2010	1.2%		8.7		3.7	-7.6%	-5.1%	0.9
Total Number of Households, 2010	28,445		762,995		1,108,307	5,845	418,735	2,324,327
Persons Per Household	2.55		2.69		2.79	2.46	2.74	2.65
Median House Unit Value, 2010 [2]	$70,333		$94,767		$121,683	$98,620	$69,229	$90,926
Total Employment, 2010	21,641		746,759		1,108,395	2,206	321,969	2,200,970
Per Capita Income, 2010 [2]	$17,846		$19,842		$21,970	$17,151	$16,794	$18,720
Household Income, 2010 [2]	$30,821		$39,749		$45,057	$30,003	$31,297	$35,385
Total Value Added by Manufacturing, 2007 (millions) [2]	$1,068.1		$37,054.8		$49,560.6	$885,672	$9,671.6	$983,027.1
Retail Sales, 2007 (millions) [2]	$712.6		$25,287		$40,208.9	$1,216.2	$11,490.9	$78,834.7
Wholesale Sales, 2007 (millions) [2]	$309.7		$38,104		$31,942.3	$186.9	$2,525.8	$73,068.7
Total Number of Farms, 2007	2,332		18,662		12,454	2,682	19,416	55,546
Total Acres in Farms, 2007	803,925		9,062,089		2,947,472	749,266	2,640,206	16,202,958
Total Value of Farm Products Sold, 2007 (millions) [3]	$345.2		$4,092.6		1119.3	$237.3	$3,869.4	$9,663.8

[1] Statistics presented to represent the closest year to 2010 as available by the US Census Bureau, QuickFacts
[2] US Census Bureau values presented in 2010 dollars
[3] Values updated from 2007 to 2012 dollars
[4] Information not disclosed

c. Demographic Setting. When reviewing the specific demographics of the areas along the Mississippi River, it is evident how the regional economies are reliant, not only on the waters of the River itself, but on the agricultural and industrial bases which have developed as a result of the River. Appendix G, *Economics,* provides a comprehensive discussion with detailed demographic statistics by county. An almost direct correlation exists between the number of persons residing in a specific area and the economic opportunities (especially economic and industrial activity) available in that area. Consequently, economic and industrial activity is used as an indicator of labor requirements and of local demands for community facilities and public services.

i. Population. Population growth is a direct reflection of the economic growth of an area. Population levels are good indicators of the size of an urban area and its land use needs such as residential, commercial, and other urban uses. Population statistics are also the basis for any other economic parameters such as per capita income (PCI), persons per household (PPH), population density, etc. Population for the total area exceeded 6.4 million in 2010, an overall growth of 3 percent over the 6.2 million people reported for 2000. Section V of this Report details totals by county and parish.

Historically, population totals for the overall region have gradually increased. However, there have been some periods of outmigration in localized rural areas where the number of persons moving out of an area was greater than the combined number of immigrating residents and the natural population growth. The Mississippi Delta suffered the greatest reduction in the total number of persons living in the area. However, growth statistics show the overall study area population has increased by over 500,000 people from 1960 to 1990 or 14 percent over the 30-year period.

Population growth within the study area has fluctuated from area to area based on varying factors. In many cases, areas within counties in close proximity to large metropolitan centers have enjoyed substantial population growth. This is evident in reviewing the population trends of counties which encompass large cities. These urban centers offer a diversified economic base of jobs, industry, and services which provide for the basic needs of a large population—employment, income, and housing.

Although the area is predominantly rural, there are over 50 cities situated along the Mississippi River that have populations of 10,000 people or greater (table II-7). There were also over 100 towns with populations between 2,500 and 10,000 people during the last Census. The largest population centers impacted by the MR&T Project are the Metropolitan Statistical Areas (MSA), which are the major commercial, services, and industrial centers for regional areas. Among these are Louisville, Pine Bluff, and West Memphis, AR; Baton Rouge, Monroe, and New Orleans, LA; St. Louis, MO; and Memphis, TN. In addition to their close proximity to the Mississippi River, each of the major metropolitan centers has international air service and is accessible by multiple Interstate and Federal highway systems. Thus, when floods of the magnitude of the 2011 occur, disruptions of numerous services take place.

ii. Housing. Data reported on housing units provide insight into significant social developments that influence the economic activity of an area. According to the latest Census, there were 2.3 million housing units located in the economic base area in 2010. The number of PPH for the MR&T area compares with the national average. Applying the total population to the total number of households, the number of PPH for the 119-county area was estimated to be 2.65 PPH for 2010. The national PPH for 2010 (2.59) is only slightly lower. These numbers reflect a trend (i.e., smaller families) that has been occurring nationally in recent decades.

The total median value of housing units, presented in 2010 dollars, ranged from highs of $203,000 and $201,000 in Plaquemines and St. Tammany Parishes, LA, respectively, to lows of $46,000 and $44,000 in Quitman County, MS, and East Carroll Parish, LA. In comparing state totals, Illinois had the highest housing value at $202,500. The national value for 2010 was reported to be $188,400.

Table II-7. Urban Areas in the Economic Base Area [1]

SWL	MVM	MVN	MVS	MVK
Arkansas	**Arkansas**	**Louisiana**	**Illinois**	**Arkansas**
Batesville	Blytheville	Abbeville	Carbondale	El Dorado
Little Rock	Forrest City	Baton Rouge		Pine Bluff
	Helena-West Helena	Crowley	**Missouri**	
	Jonesboro	DeRidder	St. Louis	**Louisiana**
	Paragould	Hammond		Alexandria
	Searcy	Houma	**Illinois/Missouri**	Bastrop
	Stuttgart	Kenner	Cape Girardeau/	Monroe
		Lafayette	Jackson	Ruston
	Illinois	Lake Charles		Vidalia
	Cairo	Metairie		
	Cape Girardeau-	Morgan City		**Mississippi**
		New Iberia		Batesville
	Missouri	New Orleans		Clarksdale
	Jackson	Opelousas-Eunice		Cleveland
	Kennett			Greenwood
	Sikeston			Greenville
				Grenada
	Missouri/Illinois			Indianola
	Jackson			Natchez
				Tunica
	Kentucky			Vicksburg
	Paducah			Yazoo City
	Tennessee			
	Bartlett-Collierville-Germantown-Memphis			
	Brownsville			
	Dyersburg			
	Humboldt			
	Jackson			
	Martin			
	Kentucky/Tennessee			
	Union City			

[1] Places with greater than 10,000 people

d. Economic Setting. Economic conditions can be described by parameters such as labor force and employment, earnings and income, agricultural activity, and industrial and business activity.

i. Employment. Total employment in the study area represents the number of wage and salary employees and the number of proprietors. Total private nonfarm employment for 2010 was estimated to be approximately 2.5 million people for the total economic base area, a 32 percent growth since 1990. The total employment in the study area in 1990 was estimated at 1.9 million, which was a 33 percent increase over the 1970 employment of 1.4 million. The majority of the economic base employment occurs in counties with large urban populations (e.g., the MSAs of Little Rock, Memphis, New Orleans, and St. Louis).

ii. Income. In 2010, the average per capita income in the economic base area ranged from a low of $11,800 in Lake County, TN, to a high of $29,300 in St. Tammany Parish, LA. Overall, PCIs for the counties averaged about $19,831 per person in 2010 in the MR&T area. However, the PCI for the majority of the states was much higher, as follows, from highest to lowest:

Illinois	$28,782	Missouri	$24,724
Tennessee	$23,722	Louisiana	$23,094
Kentucky	$22,515	Arkansas	$21,274
Mississippi	$19,977		

In comparison, the national PCI was $27,334 for 2010. Based on detailed socioeconomic studies, the major sectors contributing toward total earnings are the services, transportation, manufacturing, retail trade, government, and farming industries. Although farming and forestry have historically been major enterprises in the past, services and manufacturing have become increasingly important to the economy over the last decades. Much of this is due to increased efforts toward mechanization and industrialization of production processes and the infiltration of a diversity of industries into the region. Services and manufacturing were the leading contributors to earnings in 2010.

iii. Agriculture. Favorable agricultural characteristics have been significant factors in the development of land use patterns in the area. Historically, agricultural resources have been important to the economy of the region. However, along with industrial expansion and the increased commercialization and mechanization of farms, farming operations have followed a national trend of consolidation resulting in fewer farms with larger acreages. In 2007, there were 55,546 farms in the economic base area comprising 16.2 million acres, with an average size per farm of 292 acres.

The total value of farm products sold in 2007 was estimated to be $9.7 billion (indexed to 2012 dollars). As a major contributor to the economies of many counties in the area, agricultural production, especially in the rich Mississippi River Delta lands, remains a viable industry in the region.

SECTION III

THE 2011 FLOOD

A. INTRODUCTION

The 2011 Mississippi River Flood broke numerous stage records and produced the highest flows ever recorded along the waterway from Cairo to the Morganza Floodway (below the Morganza Floodway all record flows date to before floodway construction). River stages and flow rates were comparable to the major floods of 1927 and 1937. Well above-average precipitation fell throughout the Mississippi, Missouri, and Ohio River Valleys from January through early May. Several areas across the Mississippi Valley reached flood stage beginning in late February. In April, two major storm systems deposited record levels of rainfall on the Mississippi River watershed. That rainfall combined with the springtime snowmelt resulted in the river and many of its tributaries swelling to record levels by the beginning of May.

The primary meteorological factors that led to the historic Mississippi River Flood of 2011 included above-normal snowfall over the Upper Mississippi Valley, elevated river levels from heavy rain events from February to April, and a very heavy rain event the end of April/beginning of May. Heavy snow in December 2010/early January 2011 and again at the end of February/beginning of March led to 150 to 300 percent of normal SWE (snow water equivalents) on the ground over Minnesota and Wisconsin. Cold temperatures delayed the melting process until the third week of March, which allowed for the crest from the snow to reach the confluence of the Mississippi and Ohio Rivers at the end of April.

Heavy rains that fell over the Ohio and Middle Mississippi Valleys between the end of February and the middle of March produced the 14th highest historical stage at Cairo on March 18. The river fell through the end of April, but rain occurred once again at the beginning of April producing river stages of 9 feet above flood stage at Cairo by the middle of April. At that time, very heavy rains began and lasted from the middle of April through the beginning of May over the watershed from Arkansas City to Chester and over the Lower Ohio Valley.

Two week totals from April 19 to May14 of 8 to16 inches of rain occurred over the Mississippi watershed from Arkansas City to Caruthersville and amounts of 12 to 22 inches occurred over the watershed from Caruthersville to Chester and over the Lower Ohio Valley. These amounts were 600 to 1000 percent of normal rainfall for that time period. With the addition of the water from 150 to 300 percent of normal snow water equivalents over Minnesota and Wisconsin which melted and reached the confluence of the Mississippi and Ohio Rivers in conjunction with the very heavy rains and already elevated river levels, river stages exceeded record levels at the confluence of the Mississippi and Ohio Rivers on April 29 and at downstream locations as the flood progressed.

B. METEOROLOGICAL AND PHYSICAL CONDITIONS

Heavy snow in December 2010 and January 2011 produced snow water equivalents over the watershed north of Rock Island of 2 to 6 inches by the end of January. One inch or less of snow water equivalents were on the ground over the watershed from St Louis to Rock Island. A heavy snow storm struck the entire Mississippi watershed during the first and second weeks of February, resulting in 3 to 6 inches of snow water equivalent totals to the north of Rock Island and 3 inches or less of snow water equivalents from Natchez to Rock Island. Above normal temperatures over the Mississippi watershed the weekend of February 12 to 13 resulted in all of the snow to the south of Rock Island, IL melting by February 16. River ice coverage of 70 to 100 percent along the mainstem

Mississippi River to the north of St Louis also began its initial break-up at this time causing some ice jam flooding. Due to the snow melt and ice break-up, minor flooding was experienced along the mainstem Mississippi River from Grafton to Hannibal during the third week of February and minor to moderate flooding was occurring over many tributaries in Iowa, Missouri, and Illinois. Also due to snow melt, the Ohio River at Cairo (the confluence of the Mississippi and Ohio Rivers) was predicted to crest at 38.0 feet (flood stage is 40.0 feet) on March 1. By the weekend of February 19 to 20, the only snow remaining over the Mississippi watershed was 2 to 6 inches of snow water equivalents to the north of Dubuque.

A strong low pressure area moved out of the Southern Plains on February 24 and across the Middle Mississippi and Ohio Valleys, bringing rainfall amounts of 1 to 4 inches to the watershed from Helena, AR to St Louis, MO and snowfall amounts to 7 inches (1/2 inch SWE) to the watershed north of St Louis. Ten tornadoes and 202 damaging winds incidents occurred as the system moved through the watershed. A second heavy rain event of 1 to 4 inches occurred over the watershed from Greenville to Rock Island on February 27 and 28. After these events, minor to moderate flooding was being experienced along the mainstem Mississippi from Osceola to Grafton and on numerous tributaries in Missouri and Illinois and the Ohio Valley. The Ohio River at Cairo had risen above flood stage to 44.3 feet on March 1 with a forecasted crest of 48.0 feet on March 7.

A third round of 1 to 4 inches of rain occurred March 4 and 5 across the watershed to the south of Dubuque with snow falling over the watershed north of Dubuque. Rain continued on March 8 and 9 as another low pressure area moved across the watershed, bringing snowfall amounts to 8 inches (3/4 inch SWE) over the watershed north of Dubuque and rainfall amounts of 1 to 4 inches over the watershed south of Dubuque. As a result of these rain events, minor to moderate flooding continued on the mainstem Mississippi from Osceola to Grafton; along the Illinois River downstream from Starved Rock; along the Ohio River downstream from McAlpine L&D; and over numerous tributaries over the Ohio and Tennessee Valleys and over Mississippi and Louisiana. Cairo had reached a stage of 50.7 feet on March 10 with the crest forecasted to reach 52.0 feet on March 12. The last rain event in this series occurred on March 14 to 15 where 2 inches or less of rain occurred over the watershed to the south of Keokuk.

The heaviest rains occurred locally over the Lower Ohio Valley near Cairo. This caused the River to rise to a crest of 53.41 feet on March 18, the 14th highest historical crest. At the time of the crest at Cairo, minor to major flooding was being experienced along the mainstem Mississippi River from Memphis to Cape Girardeau and along the entire Ohio River. Minor to moderate flooding was occurring along the Illinois River downstream from Peoria and over numerous tributaries to the south of St Louis. Snow began to melt over the watershed north of Dubuque on March15 with snow water equivalents of 1 to 5 inches remaining on the ground over the watershed to the north of Dubuque on March 22. These snow water equivalents were 150 to 300 percent of normal over Minnesota and Wisconsin and caused minor to major flooding along the mainstem Mississippi River beginning the last week of March. The Mississippi River at St Paul exceeded major flood stage and reached its 8th highest crest on March 29 at 19.01 feet.

The Ohio River at Cairo fell below flood stage on April 3, but rainfall amounts of 1 to 2 inches on April 8 and 9 and 1 to 4 inches on April 11 and 12 caused the river to rise again above flood stage on April 10 with a crest of 47.0 feet predicted for April 20. A second round of heavy rains began as a cold front moved through the Middle Mississippi/Ohio Valleys on April 14 to 15. Rainfall amounts of 1 to 4 inches accompanied by widespread severe thunderstorms (32 tornadoes, 396 damaging winds incidents, and 324 large hail reports on April 19) moved through the watershed from Greenville to Dubuque on April 18 to 20. With this rain, the Ohio River at Cairo was forecasted to reach a crest of 51.0 feet on

April 30. The frontal system basically became stalled over the Arkansas and Ohio Valleys from April 20 to May 2, setting up the rain event that caused the Ohio River at Cairo to exceed record levels. As the front stalled, daily rounds of heavy rains occurred over the watershed from Arkansas City to Chester with rainfall totals from April 22 to 27 of 5 to 14 inches falling. On April 28, the Mississippi River at St Louis was cresting around 34.1 feet and the Ohio River at Cairo was rising at 58.7 feet with an expected crest of 60.5 feet on May 1. The final round of rain occurred from April 30 to May 2 over the watershed from Greenville to Chester and over the Lower Ohio Valley where 2 to 8 inches fell. Cairo reached 61.0 feet during the morning of May 2 with a forecasted crest of 63.0 feet on May 5. The front finally exited the watershed and rains ended on May 3.

Two week totals from April 19 to May 4 of 8 to16 inches occurred over the Mississippi watershed from Arkansas City to Caruthersville and amounts of 12 to 22 inches occurred over the watershed from Caruthersville to Chester and over the Lower Ohio Valley (figure III-1). These amounts were 600 to 1000 percent of normal rainfall for that time period (figure III-2). The addition of 150 to 300 percent of normal snow water equivalents over Minnesota and Wisconsin (figure III-3), which melted and reached the confluence of the Mississippi and Ohio Rivers in synchronization with the heavy rains, and elevated river levels from early April rains were the key factors that led to the 2011 Flood.

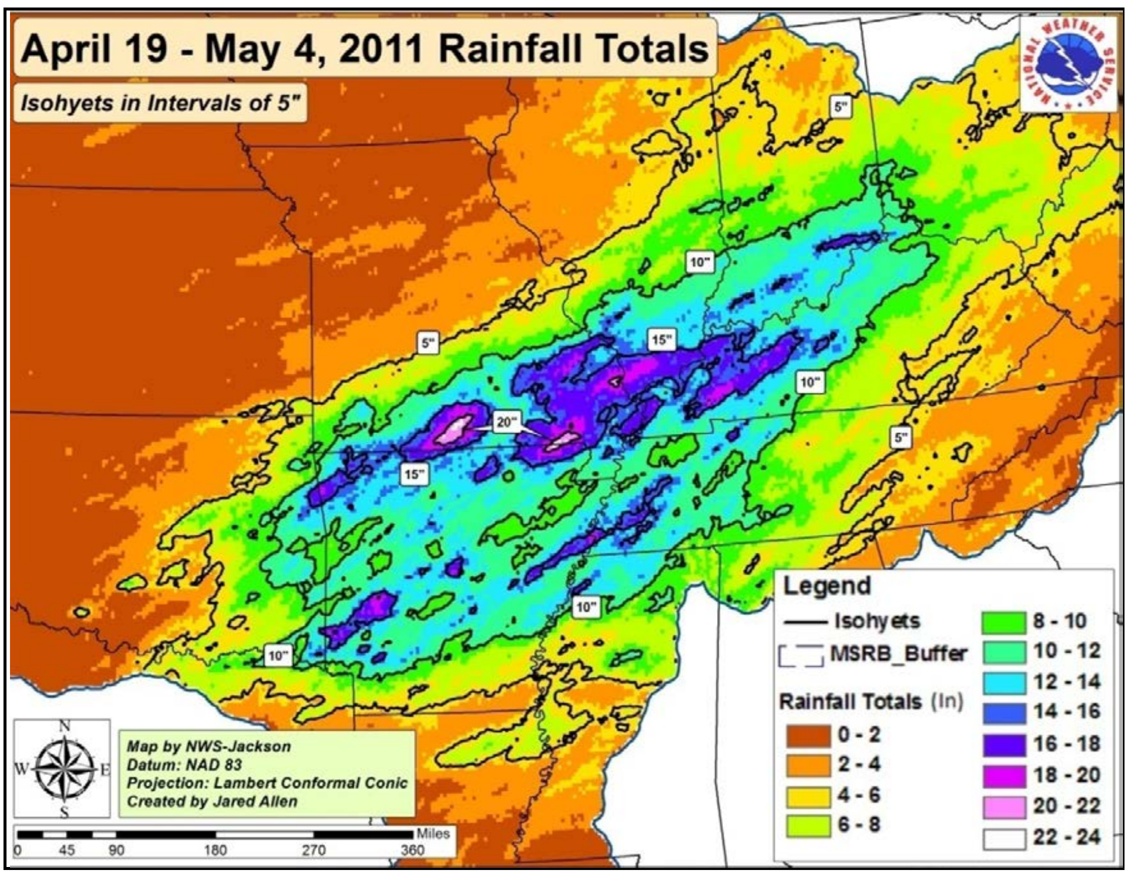


Figure III-1. Rainfall Totals Over Portions of the Lower Mississippi and Ohio Watersheds From April 19 to May 4, 2011

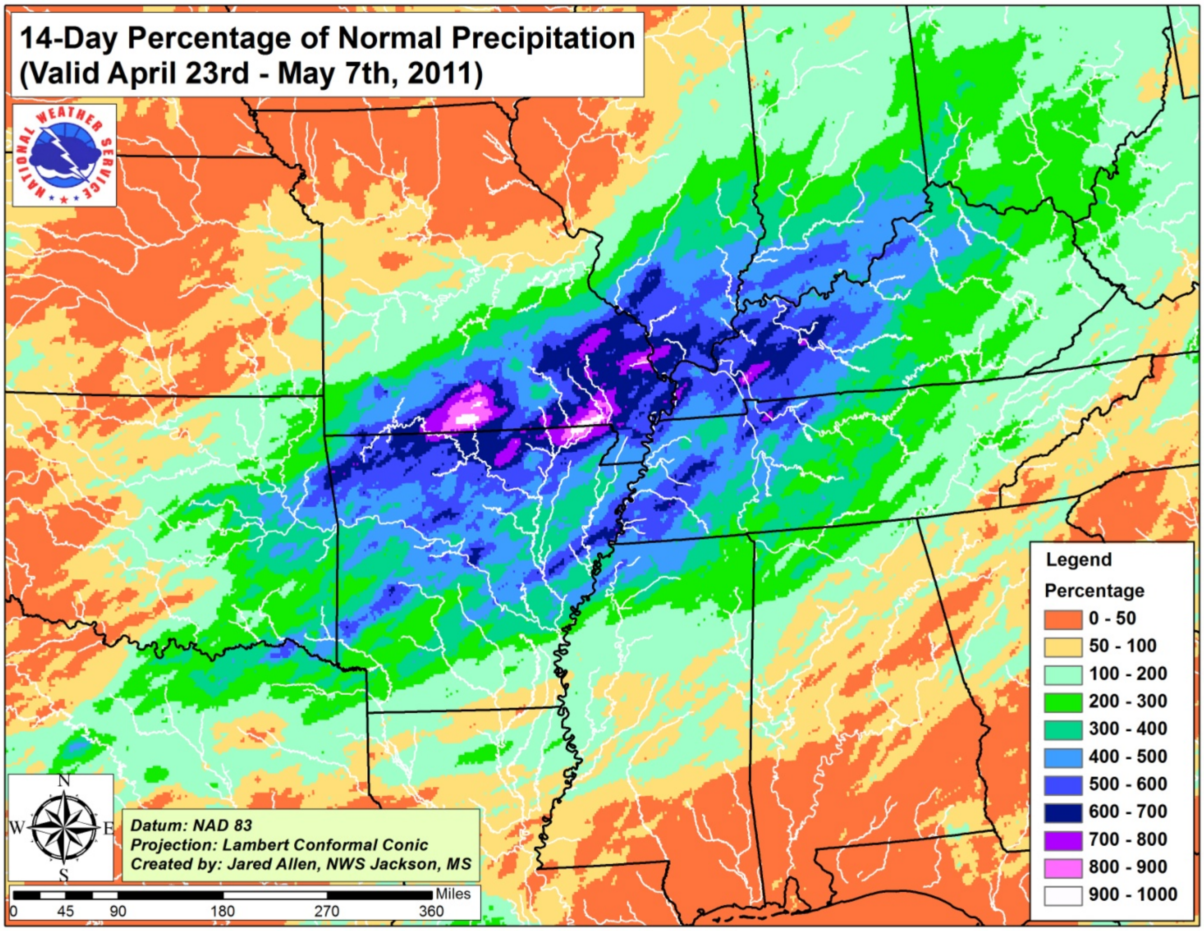


Figure III-2. Percent of Normal Precipitation Over Portions of the Lower Mississippi and Ohio Watersheds From April 23 to May 7, 2011

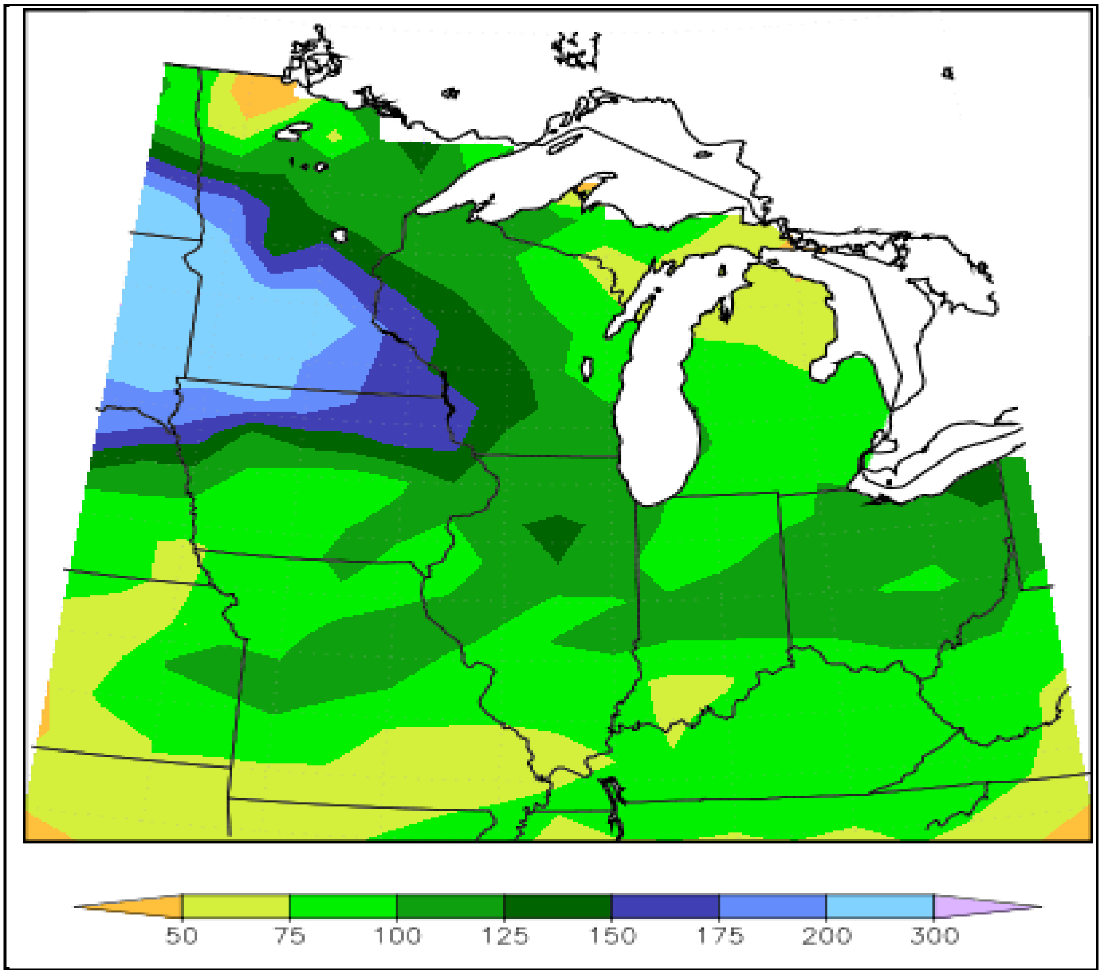


Figure III-3. 150 to 300% of Normal Snow Water Equivalents Over the Watershed North of Dubuque, IA From December 1, 2010 to February 28, 2011 (Source: Midwestern Regional Climate Center, Illinois State Water Survey, UI at Urbana-Champaign)

C. HISTORICAL FLOODS

There were major floods on the LMR in 2011, 2008, 1997, 1995, 1993, 1983,1973, 1950, 1937, 1929 and 1927. Past floods can provide some historical context for the 2011 Flood. Figures III-4 through III-14 are hydrographs for key locations on the Mississippi, Ohio, and Atchafalaya Rivers and illustrate how the 2011 Flood and other floods of note affected river stages at those locations, relative to flood stage and the PDF at each location.

Please note that physical gage locations may have varied slightly during the historical record. Because of this, hydrograph data may not be directly comparable between years at the same gage.

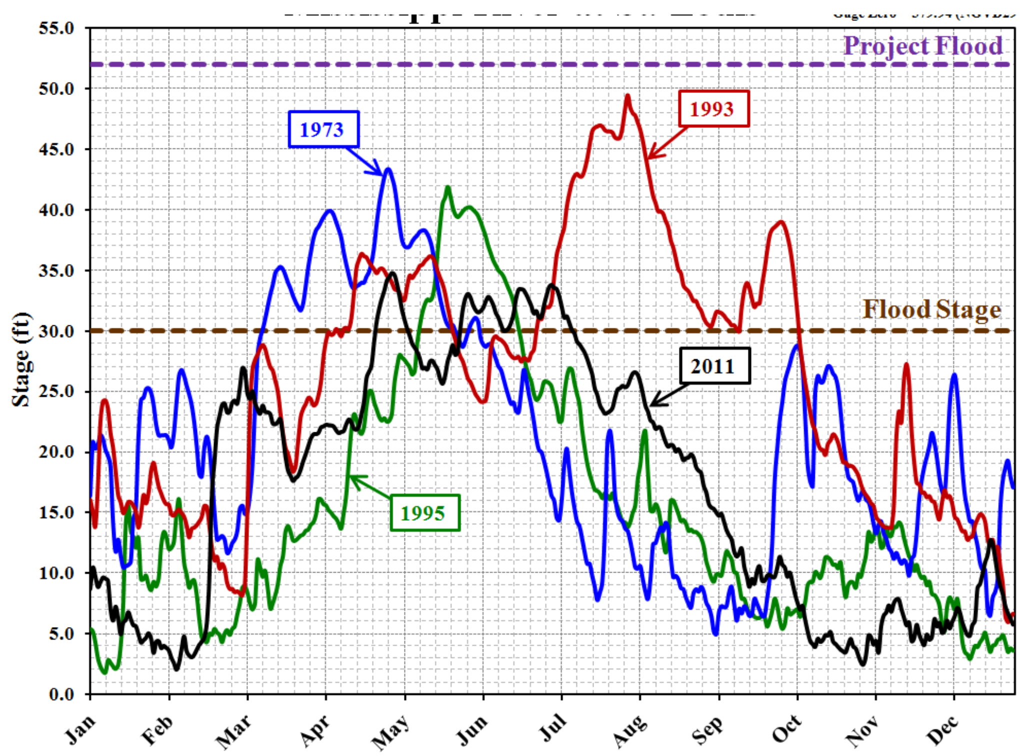


Figure III-4. Mississippi River Hydrograph, St. Louis, MO
[Gage Zero=379.94 (NGVD29), project flood refers to urban St. Louis protection (non-MR&T projects)]

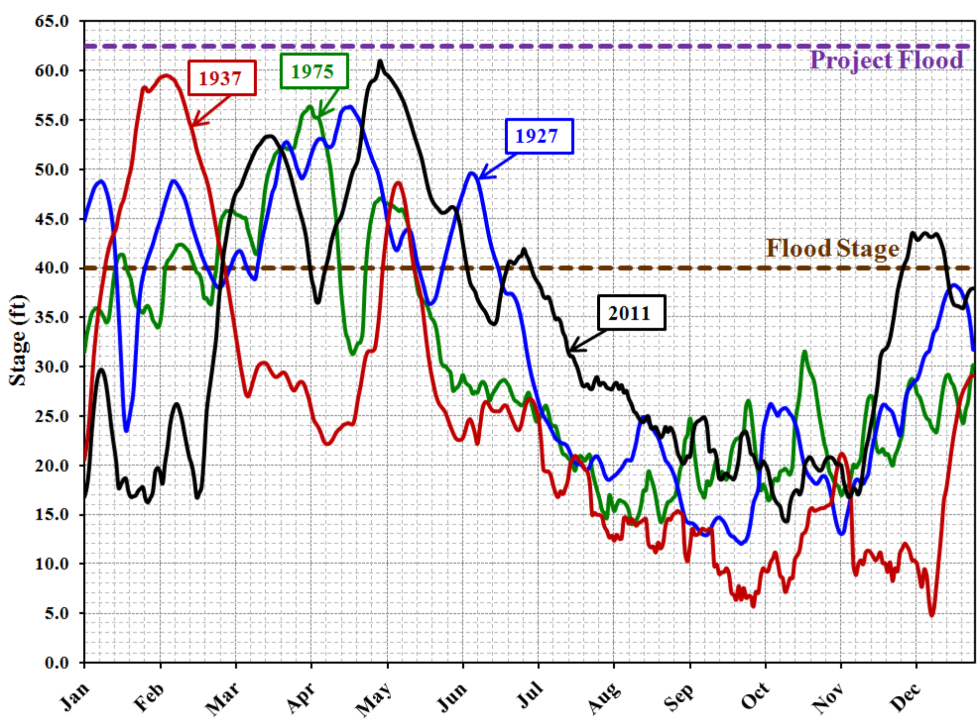


Figure III-5. Ohio River Hydrograph, Cairo, IL - Gage Zero=270.474 (NGVD29)

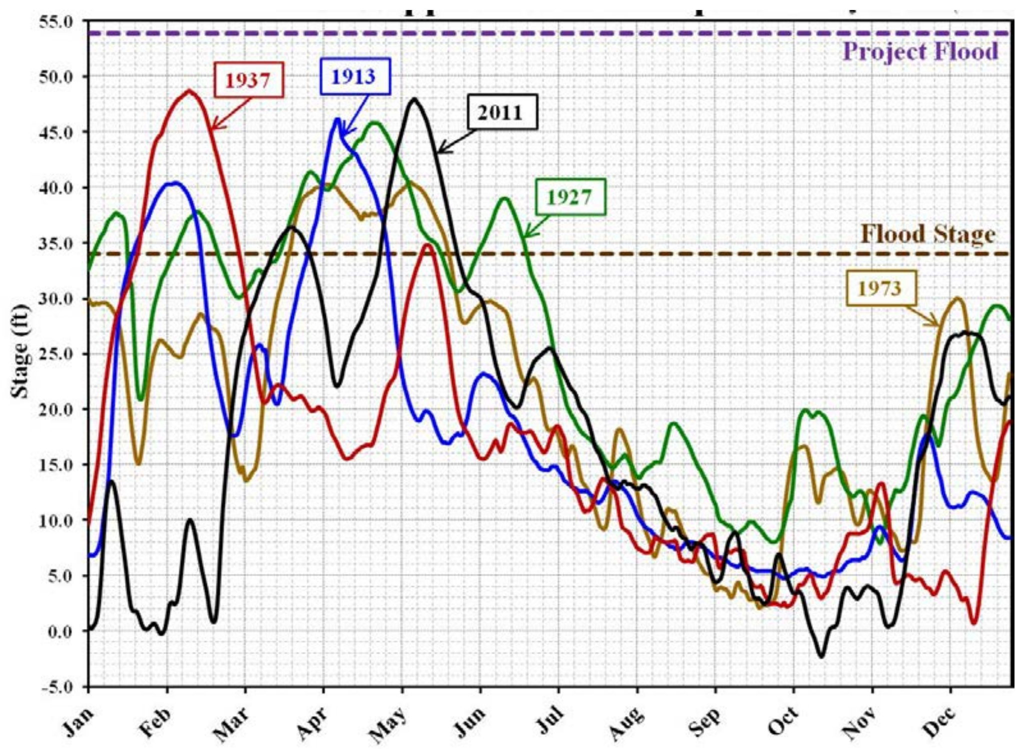


Figure III-6. Mississippi River Hydrograph, Memphis, MO - Gage Zero=183.91 (NGVD29)

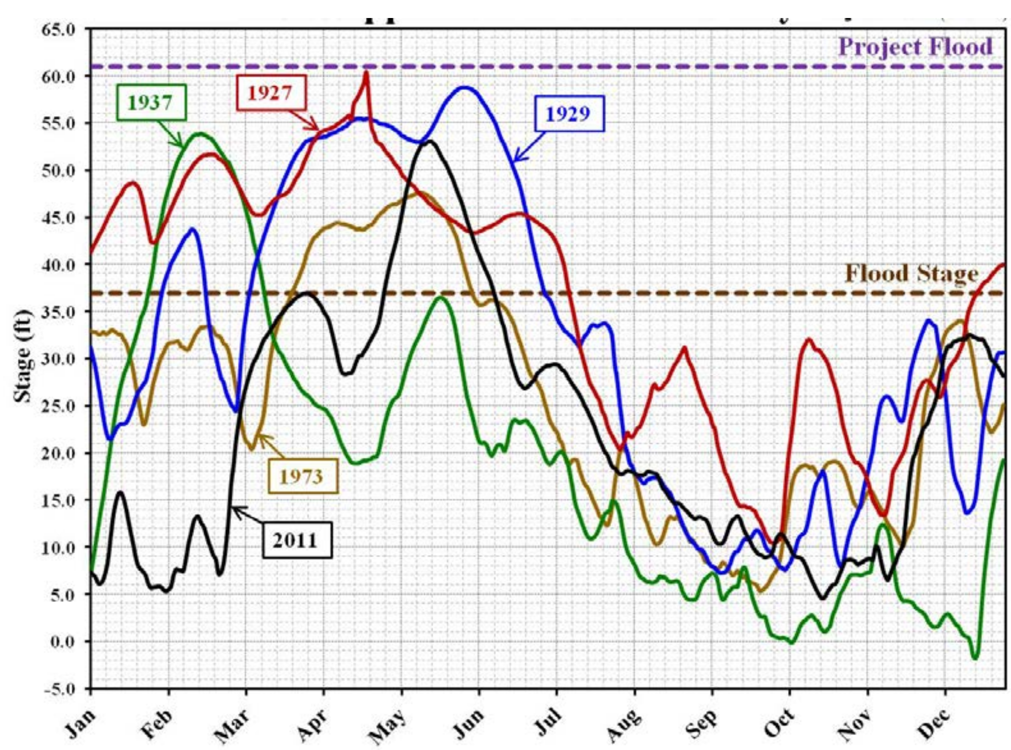


Figure III-7. Mississippi River Hydrograph, Arkansas City, AR - Gage Zero=96.66 (NGVD29)

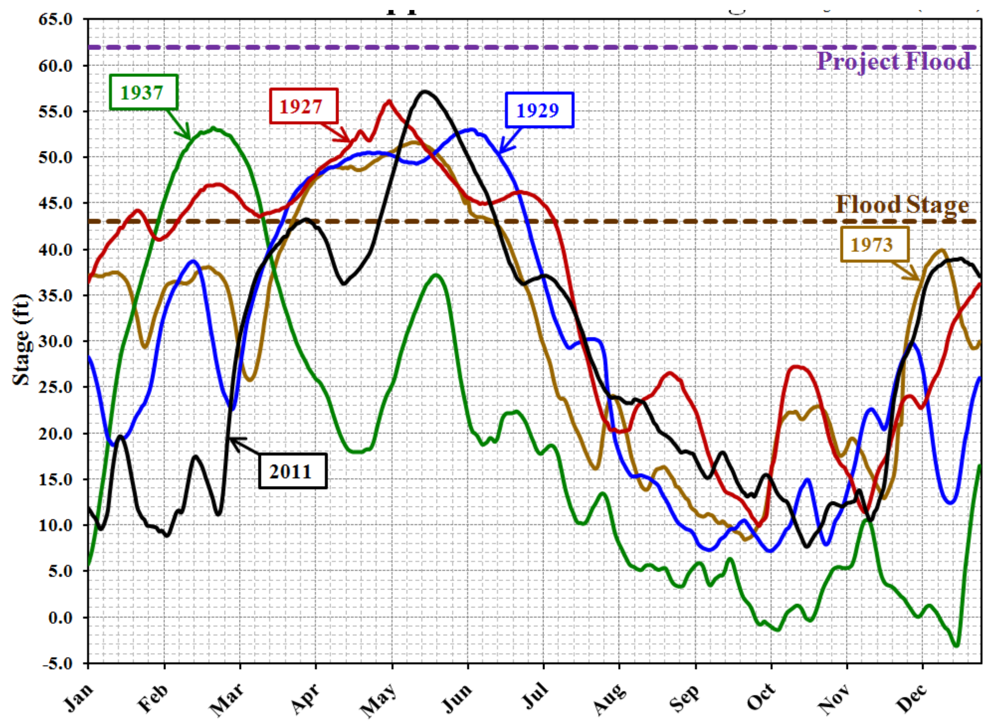


Figure III-8. Mississippi River Hydrograph, Vicksburg, MS - Gage Zero=46.23 (NGVD29)

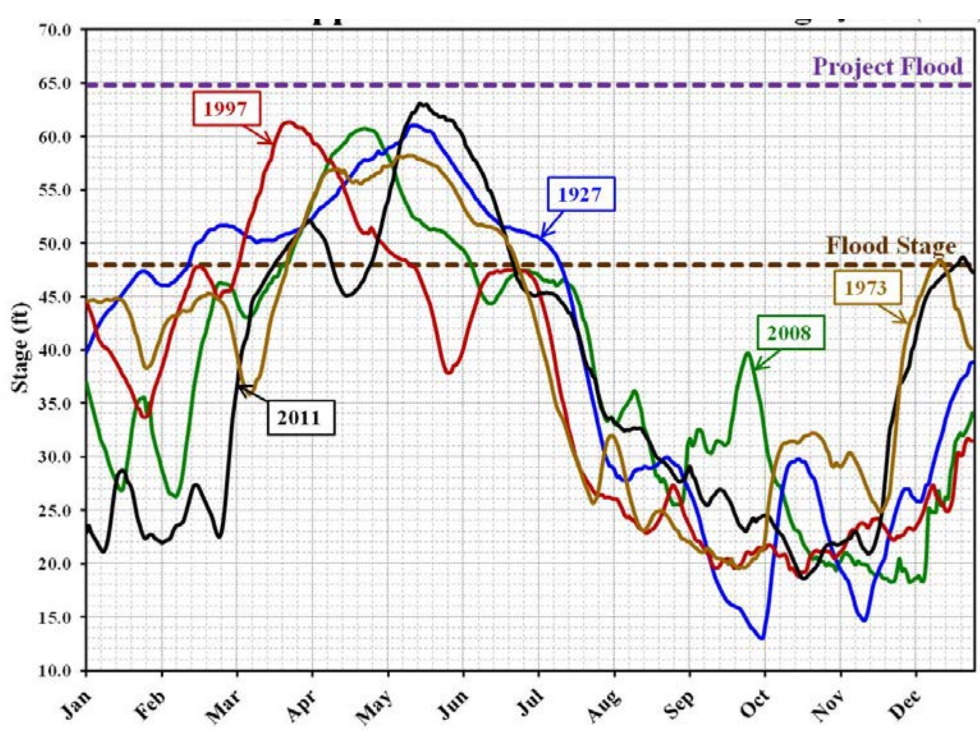


Figure III-9. Mississippi River Hydrograph, Red River Landing, LA - Gage Zero=0.0 (NGVD29)

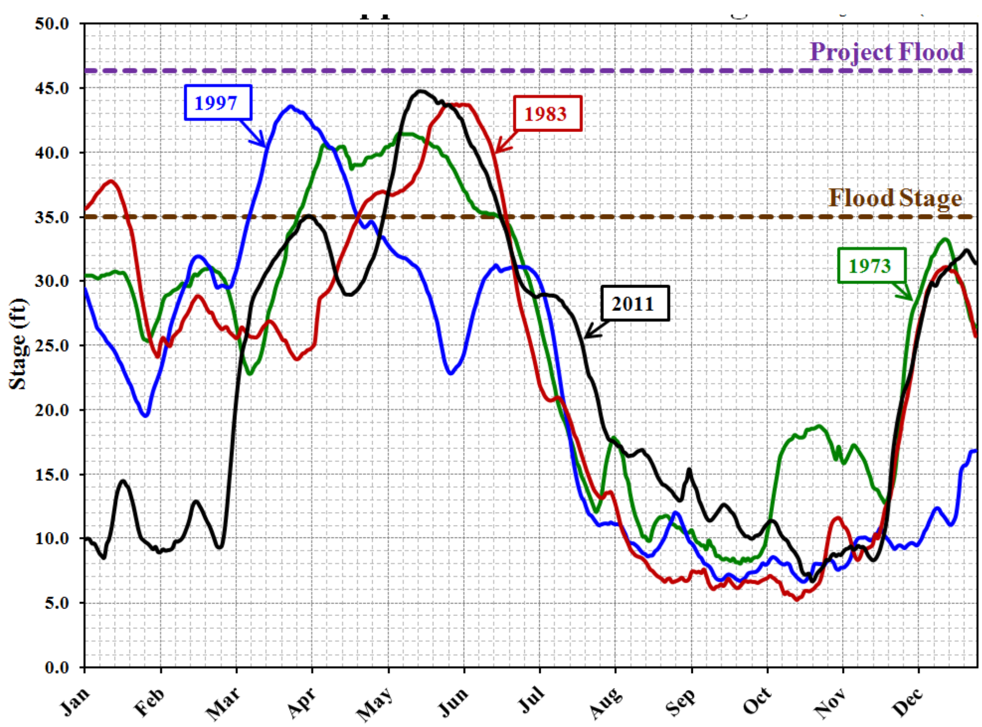


Figure III-10. Mississippi River Hydrograph, Baton Rouge, LA - Gage Zero=0.0 (NGVD29)

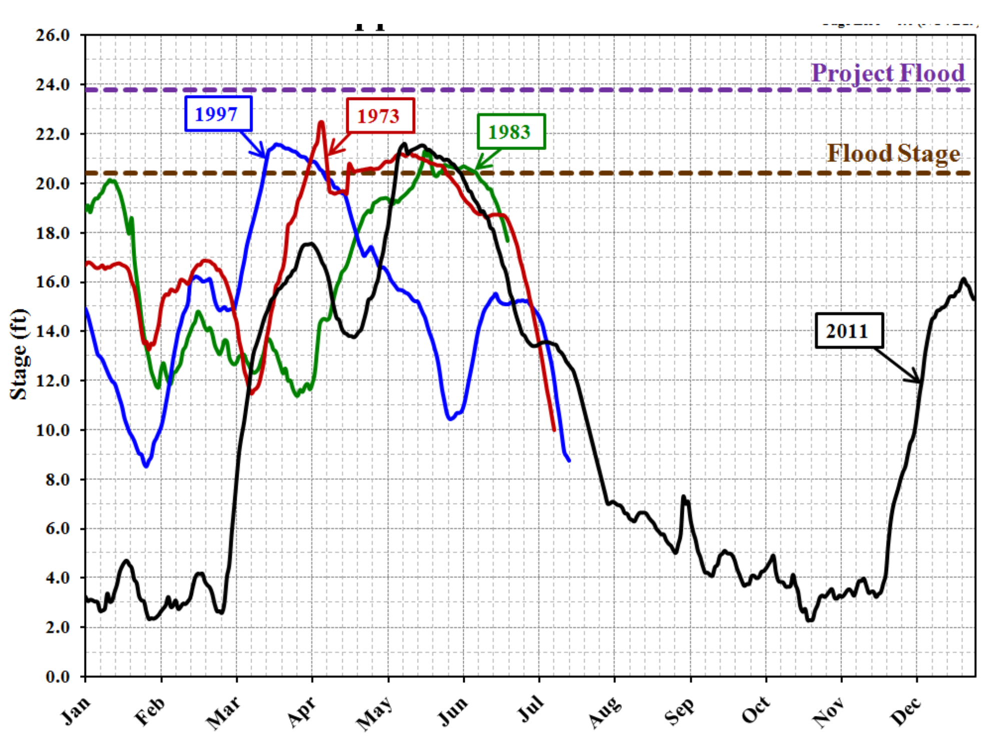


Figure III-11. Mississippi River Hydrograph, Bonnet Carré, LA - Gage Zero=0.0 (NGVD29)

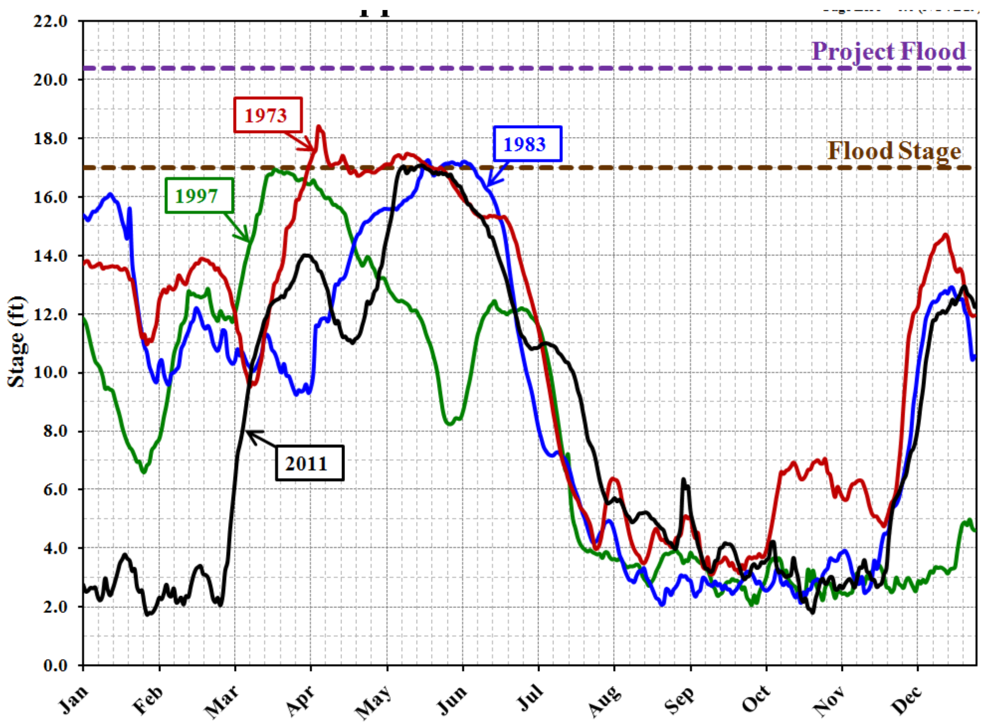


Figure III-12. Mississippi River Hydrograph, New Orleans, LA - Gage Zero=0.0 (NGVD29)

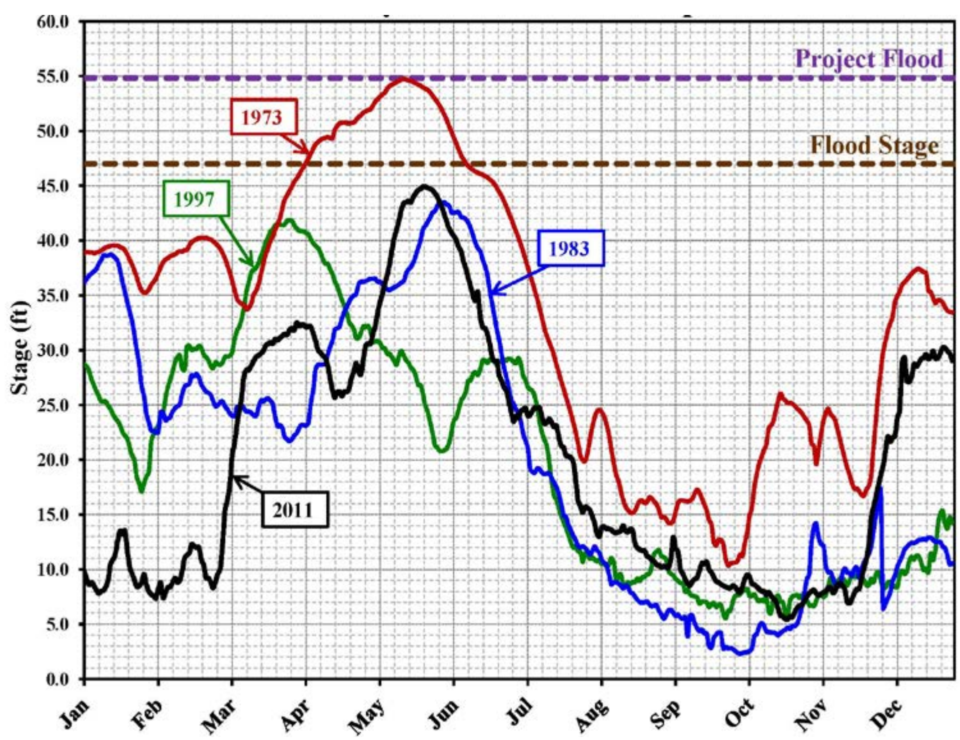


Figure III-13. Atchafalaya River Hydrograph, Simmesport, LA - Gage Zero=0.0 (NGVD29)

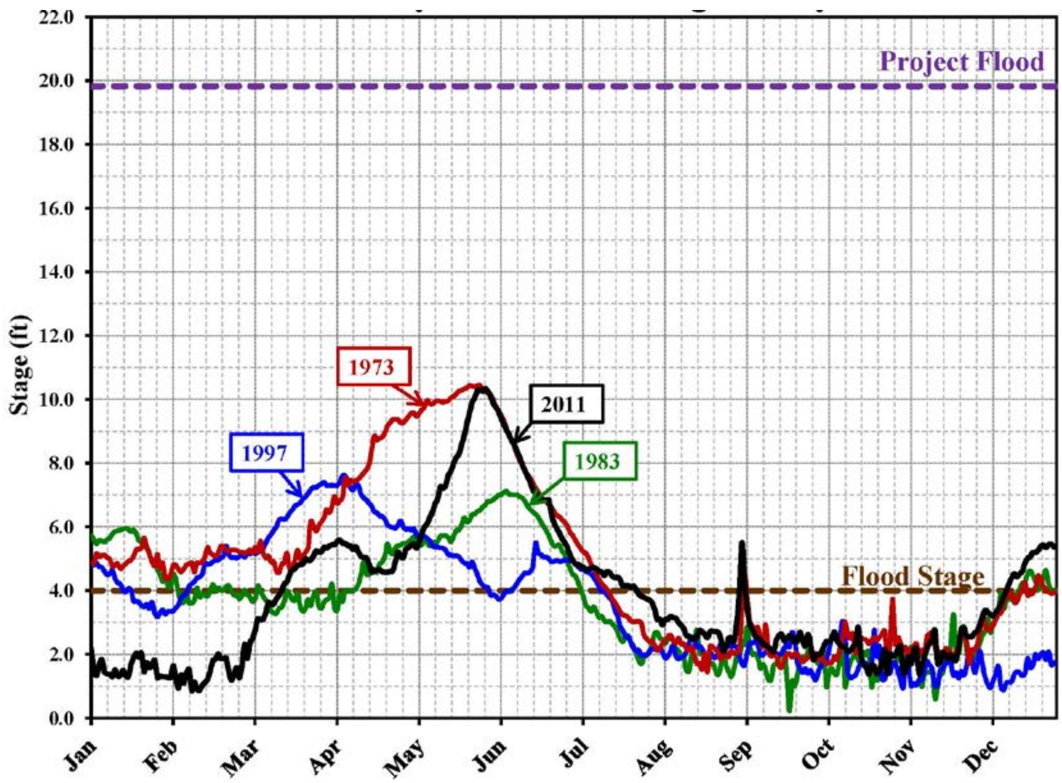


Figure III-14. Atchafalaya River Hydrograph, Morgan City, LA - Gage Zero=0.0 (NGVD29)

SECTION IV

MR&T OPERATION AND EMERGENCY ACTIVITIES

A. INTRODUCTION

Under the authority of Public Law 84-99, the Corps executed its responsibility to support local interests in all phases of flood fighting. The MR&T System was approximately 11 percent incomplete at the time of the 2011 Flood; however, in combination with extensive emergency flood fight efforts, it generally performed as designed.

Emergency flood fight measures included ringing sand boils, constructing water berms, blocking culverts and ditches to prevent inflow of floodwaters, constructing erosion control measures, and raising deficient sections of the mainstem Mississippi River Levee to authorized grade. Crest stages during the 2011 Flood varied between levels 9 feet below the Project Design Flood (PDF) flowline to stages exceeding the PDF flowline. For the first time, the Morganza, Bonnet Carré and BPNM floodways were operated during a single event. The BPNM Floodway operation was the first since 1937 and only the second in its history, while the Morganza operation was the first since 1973 and also the second in its history. The Bonnet Carré Spillway was operated for the tenth time in its history. Each of these floodway operations reduced stages by several feet, both downstream of the floodways and for varying distances upstream, while operations at many reservoirs also provided stage reduction benefits. Although backwater effect occurred on several rivers, none of the MR&T authorized backwater areas were operated during the 2011 Flood because river stages remained below their operation level and the backwater levees did not overtop.

The following sections summarize the plans used to guide operation of the MR&T System and the actions taken in response to the 2011 Flood. They also present the results of an assessment of the successes and vulnerabilities of each major MR&T System component based on the 2011 Flood. Later, the Summary and Conclusions Section presents a coordinated analysis of the conclusions that can be drawn from the overall systems perspective. The Recommendations Section compiles all recommendations, based on broad-based considerations and presents them within the context of the performance and operation of the entire system.

B. EMERGENCY OPERATIONS PLANS

Each District maintains an Emergency Operation/Action Plan for the operation of MR&T System components within its AOR. Water control structures are operated in accordance with approved Water Control Plans. These plans contain the process information, roles and responsibilities; decision criteria, communications guidance, and detailed information to address known trouble spots and the operation of a variety of features and activities specific to each district. They also include plans/manuals, flood fight rosters, standard operating procedures and phased flood fight deployment guidance. Emergency Operation Plans are generally reviewed and updated annually and as new information becomes available. MVD also maintains plans for actions and components for which it has operational or oversight responsibilities. In addition to Corps' plans, local levee districts, states, counties and similar authorities also have emergency plans that are used, adapted, and adjusted for each flood event. The Emergency Response community evaluates plans and continually incorporates new ideas and new information in preparation for flood seasons. All of these plans are tested during events like the 2011 Flood and the lessons learned are used to improve responses to future challenges. The significant issues that arose and the deficiencies and vulnerabilities exposed during the 2011 Flood are discussed along with the associated MR&T System components in Section IV.D.

C. FLOOD FIGHT SUMMARY BY DISTRICT

Each district knew, from experience with past high water events, where known trouble spots were and began monitoring these problem areas and remediating them as needed. This allowed the districts to respond more quickly to problems in new areas as well as the historic problem areas. Each district closely monitored and documented the issues with both new and historical trouble spots so that post-flood inspections and damage assessments would be well informed. The following sections summarize flood fight activities and related deficiencies and damages. Additional details are provided for each MR&T System component in the Appendices.

1. St. Louis District

a. Flood Fight Summary. MVS Commander, signed a Declaration of Emergency at 15:00 April 21, 2011, due to a significant flood threat on the Upper Mississippi River. This initiated Phase I of the MVS Emergency Response Plan. The MVS EOC was activated at Level I on April 21, Level II on April 25 and Level III on May 1 in response to rising water levels along the Mississippi River and at Wappapello Lake. Phase II of the flood fight began April 25 when the Mississippi River exceeded 59 feet on the Louisiana, MO gage. The MVS EOC returned to Level I activation June 20, and the flood fight ended June 23, when the stage at Louisiana receded below 19 feet. At that time, the MVS EOC was deactivated.

b. Funding Details

3112 MR&T Appropriation Direct	$ 687,000
3125 FCCE Emergency Operations	$1,540,000
Total Flood Fight	**$2,227,000**

c. Chronology of Flood Fight Activities. Table IV-1 shows the chronology of MR&T flood fight activities in the St. Louis District. All times are CDT.

Table IV-1. Chronology of MR&T Flood Fight Activities – St. Louis District

Date	River Events	MVS Events	Other Events
21-Apr	Louisiana stage exceeds 19 feet (forecast crest 21.0 on 27 Apr)	MVS Commander signs emergency declaration; MVS enters Phase I flood fight in Louisiana & Missouri, activates EOC to Level II, requests and receives $225k of 210 funds.	
24-Apr	Wappapello Lake elevation 361.87	Wappapello Lake- evacuated Greenville and Peoples campground; preparing to release 10,000 cfs when they reach elevation 380, in accordance with Water Control Plan.	
25-Apr	Wappapello Lake elevation 372.88	COL O'Hara visits Wappapello Lake	
26-Apr	Wappapello Lake elevation 382.65	Yesterday's rainfall threatens to push lake levels to exceed overflow section, el 397.74. MVS is evaluating two options - get a deviation from MVD Water Control to release more water now and/or flood fight the spillway. An additional inch of rain would make flood fight feasible; additional 2 inches of rain would make it a questionable option.	
27-Apr	Wappapello lake elevation 389.91	MVS working to construct rock dike to flood fight the spillway. Contract initiated 27 Apr	
28-Apr	Wappapello lake elevation 393.99	Rock berm will be raised to 398.5 by tonight. 16" pump will be placed to reduce water between rock berm and spillway.	
29-Apr	Wappapello lake elevation 396.39	Forecasted crest is 397.0. Two additional pumps will be placed to reduce the water between the rock berm and spillway. Rock dike has been degraded to el 397.3 from 398.5 after a deviation was disallowed by Dam Safety during the deviation coordination process.	
30-Apr	Wappapello lake elevation 396.63	Preparing for high water; moving equipment, materials, and supplies from Admin building to Visitors Center and Redman Creek picnic area. Redman Creek picnic shelter will be used as one of the command centers if Admin building becomes inaccessible. Personnel placing walls at the shelter. The drainage path for the predicted flow over the spillway is still being graded. Evacuation plans are in place and ready to be executed if/when needed.	
1-May	Wappapello Lake elevation is 396.63	Preparing for high water; rolls of plastic provided to field office. Media updated every 2 hrs	MG Walsh, congressional delegates Blunt and Emerson visit to SE MO
2-May	Wappapello Lake elevation 399.12	Rock berm overtopped at 0200. Project office evacuated but not threatened by discharge flows. Command Centers in Visitors Center and at Redman Creek being utilized. Lake stage at 1630 is 399.12. Spillway fully functioning w/ flows expected to increase from 22,850 to 25,700 cfs.	The state highway across the dam was destroyed along with the fiber optics and water lines going across the dam.
3-May	Wappapello Lake crests record level of 400.04	Spillway fully functioning with flows from 30,300 cfs.	MG Walsh visits Lake Wappapello
4-May	Wappapello Lake elevation- 399.81	Lake release 27, 200 cfs	Congresswoman Emerson visits Wappapello and Cape Girardeau area
5-May	Wappapello Lake elevation 398.48	Lake release 18,500 cfs, expected to be back to 10,000 cfs by Saturday. MVS working with MO Dept of Transportation in discussing re-opening downstream bridge/road.	Power lines are being re-established across the spillway.
6-May	Wappapello Lake elevation 398.09	Lake release 14,150 cfs. MVS continues to work with MO Dept of Transportation regarding re-opening of downstream bridge/road, scheduled for Sunday. Visitors Center has power. Open for public visits to observe the overflow.	Power lines re-established across the spillway.
7-May	Wappapello Lake elevation 397.60	Lake release 10,000 cfs	
8-May	Wappapello Lake elevation 397.06	Lake release 10,000 cfs	
9-May	Wappapello Lake elevation 396.77	Lake release 10,000 cfs.	Presidential disaster declaration DR-1980 for MO flooding

2. Memphis District

a. Flood Fight Summary. MVM Commander signed a Declaration of Emergency at 15:00 March 7, 2011, due to a significant flood threat on the Mississippi River, initiating Phase I of the Emergency Response plan of the MVM. The MVM EOC was activated at Level I on March 7 and Level III on March 14 in response to the rising water levels along the Mississippi River. Phase II of the flood fight began March 14 when the Mississippi River exceeded 52 feet on the Cairo, IL gage. The MVM EOC returned to Level I activation March 22, and the flood fight ended March 24, when the stage at Cairo receded below 49 feet, and the MVM EOC was deactivated.

MVM Deputy Commander signed a Declaration of Emergency on behalf of MVM Commander at 09:00 April 20, 2011, due to a renewed significant flood threat on the Mississippi River, reinitiating Phase I of the Emergency Response plan of the MVM. The MVM EOC was activated at Level I April 20 and Level III April 24 in response to the rising water levels along the Mississippi River. Phase II of the flood fight began April 24 when the Mississippi River exceeded 52 feet on the Cairo, IL., gage. Phase II 24-hour patrols began April 26 and continued until May 11. The MVM EOC began Level IV 24-hour operations April 26 and remained at this level of activation until May 12. The MVM EOC returned to Level I activation on May 29. The flood fight ended June 5, when Phase I monitoring of the White River was discontinued, and the MVM EOC was deactivated.

b. Funding Details

March Flood Fight

MR&T Total	**$118,000**
MRL Maintenance	$118,000
St. Francis Maintenance	$0
White River Maintenance	$0
FC&CE Total	**$310,000**
21M MRL – M	$310,000
21M St. Francis – M	$0
24M St. Francis – M	$0
March Subtotal:	**$428,000**

April-June Flood Fight

MR&T Total	**$7,591,000**
MRL Maintenance	$6,718,000
St. Francis Maintenance	$128,000
White River Maintenance	$745,000
FC&CE Total	**$8,100,000**
21M MRL – M	$2,355,000
21M St. Francis – M	$4,670,000
24M St. Francis – M	$1,075,000
April-June Subtotal:	**$15,691,000**

TOTAL FLOOD FIGHT: $16,119,000

c. Chronology of Flood Fight Activities. Table IV-2 on pages IV-5 through IV-11 shows the chronology of flood fight activities in the Memphis District. All times are CDT.

Table IV-2. Chronology of Flood Fight Activities – Memphis District

Date	River Events	MVM Events	Other Events
26-Feb	Stage at Cairo exceeds flood stage (40’)		
27-Feb	Cairo stage: 41.4		St. Johns Levee and Drainage District closes St. John's Bayou floodgates
7-Mar	Cairo stage exceeds 49’ (forecast crest 50.5 on 3/11).	MVM Commander signs emergency declaration. MVM enters Phase I flood fight in Cairo, MO and Reelfoot-Obion areas, activates EOC to Level I. MVM requested and received $35k of 210 funds. Cairo Area reports sinkhole at 11th and Commercial in Cairo (later determined to be from city pumping operations at the 10th St. station); numerous pin boils along Hwy 51 in Future City.	
9-Mar	Cairo stage: 50.2 (forecast crest 52.0 on 3/13). Slide riverside on BPNM frontline levee (Sys. 16), Levee Mile 84/0+00.	Two slides on landside of BPNM setback levee (Sys 2, Seg. 10), LMs 34/22+85 and 34/24+35.	
10-Mar	Cairo stage: 50.8 (forecast crest 52.5 on 3/15).	Backwater inside BPNM Floodway over MO Hwy. WW. Slide at BPNM frontline levee enlarged.	
11-Mar	Cairo stage: 51.4	MVM requested and received $25k of 210 funds.	
14-Mar	Cairo stage: 52.6.	MVM enters Phase II flood fight in Cairo, MO and Reelfoot-Obion areas, activates EOC to Level III. MVM requested and received $250k of 210 funds. Pin/sand boils reported in Hickman sector at Island No. 8 in KY.	
15-Mar	Cairo stage: 53.0.	Numerous boils in Cairo sector along Hwy 51 (Sys.1, Seg. 2). Some flowing readily and transporting silt.	
18-Mar	Cairo crests at 53.41.	Sand boils reported near Island 8 in KY. (Sys. 3, Seg. 11, Levee Mile 6).	
20-Mar	Cairo stage: 53.1.	Sand boils reported near Island 8 in KY. (Sys. 3, Seg. 11, Levee Mile 8, 6, & 11)	
22-Mar	Cairo stage drops below 52	MVM ends Phase II flood fight in Cairo, MO and Reelfoot-Obion areas, lowers EOC activation to Level I	
24-Mar	Cairo stage: 51.3 (forecast to continue falling below 49)	MVM ends Phase I flood fight in Cairo, MO and Reelfoot-Obion areas, deactivates EOC. Stages would exceed Phase I levels in Memphis, West Memphis, Helena, and Clarksdale; Levee Districts and Wynne Area Office monitored water levels without initiating Phase I flood fight.	
3-Apr	Cairo stage drops below 40		
9-Apr	Cairo stage exceeds 40 again		
20-Apr	Cairo stage exceeds 49’ again. Based on NWS forecast of 52 on April 30 (contingency of 58)	MVM Deputy Commander, signs emergency declaration on behalf of MVM Commander. MVM reenters Phase I flood fight in Cairo, MO and Reelfoot-Obion areas, activates EOC to Level I. MVM begins coordination calls with LRD. MVM requested and received $100k of 210 funds.	

Table IV-2. Chronology of Flood Fight Activities – Memphis District

Date	River Events	MVM Events	Other Events
21-Apr	Cairo stage: 49.8 (forecast crest 52.0 on 4/30). Forecast of daily rounds of moderate to heavy rains from Caruthersville to Hannibal including Ohio Valley. (4-8"thru 4/26). Cairo may expect 10 foot rise on gage NWS contingency forecast of 61.1 Cairo gage on 5/4.	Pin boils are active where noted in March flood fight (Cairo, Island 8). No change to levee slides noted in March.	
22-Apr	Cairo stage: 50.3 (forecast crest 52.0 on 4/30)		LRD began increasing Kentucky-Barkley discharges a total of 50,000 cfs and will continue thru the weekend to clear storage space in the reservoirs
23-Apr	Cairo stage: 51.0		
24-Apr	Cairo stage: 52.4 (forecast crest 58.5 on 5/3) St. Francis, Ark., stage exceeds 24 Up to 6"over lower Ohio during past 24 hours. Forecast predicts 8"of rain over next 5 days. Tornado touches down near Cairo Regional Airport.	MVM enters Phase II flood fight in Cairo, MO, and Reelfoot-Obion areas, Phase I in Upper St. Francis area. EOC activated to Level III. Coordinated coordination that had begun in March with City of Cairo to get city pumps operational.	Tennemo private levee artificially crevassed
25-Apr	Cairo stage: 54.6 (forecast crest 60.0 on 5/3) St. Francis, Ark., stage: 25.02 3-8" rain forecast north of Ark City (includes Ohio Valley).	MVM enters Phase II flood fight in Upper St. Francis area. Cairo team patrolling levees, floodwalls, pump stations and all sand boil locations. Barge loading commences, completed at 19:30. MVM press release "COE prepares to operate BPNM". Initiated Dutchtown, MO, emergency levee plan, contracting process. Seepage occurring under and through Cairo floodwall. Street collapse from March at 11th and Commercial in Cairo expanded.	Mississippi County Sheriff's Department declared a state of emergency in the Floodway and orders evacuation. KMOX radio reports Gov. of MO objects to BPNM operation.
26-Apr	Cairo stage: 56.5 (forecast crest 61.0 on 5/3, remain above 60 for 10 days). St. Francis, AR. stage: 26.0 2-5"expected from Ark City to Cape on 4/26-4/27; another 1.5 over Ohio 5/6-5/7.	Cairo, MO and Reelfoot-Obion areas begin 24-hour levee patrols. EOC activation increased to Level IV, 24-hour operation. MVM determines mainline levee at Lake County will not pass flood of 61' on Cairo gage and makes recommendation to raise low spots in the levee near Tiptonville 2' using 12K tons of crushed limestone. MVD Commander orders movement of barges to Hickman Harbor; M/V Mississippi departs Ensley Engineer Yard. MVD Commander orders land-based crews to deploy 4/27 and prepare Floodway for operation. MVM requested and received an additional $400k of 210 funds. At Fulton Co., pin boils continue to develop in the Island 8, KY area and they are ringed as necessary. Two sand boils flowing at Mile 6. Three large boils flowing at Mile 7 near existing house. Two boils flowing at Mile 8. Levee Board delivering sand bags at each location. Sand boils at Future City (Sys. 1, Seg. 5) beginning to pipe material.	Floodway evacuation continues. MO National Guard is assisting with this effort and preventing unauthorized personnel from entering floodway. Dyer County Little Levee board approved plan to intentionally breach levee as it will overtop when Caruthersville reaches 44 feet.

Table IV-2. Chronology of Flood Fight Activities – Memphis District

Date	River Events	MVM Events	Other Events
27-Apr	Cairo stage: 58.0 (forecast crest 60.5 on 5/1). St. Francis, Ark. stage: 26.5 1-3"expected between Ark City and Cape, with heaviest over Tenn/Cum. Another rain event expected over MO/ARK/lower OH on 4/30-5/1.	M/V Miss. arrives at Hickman Harbor (will take 6 hours to position at 1st loading site. MVM establishes Joint Information Center in Sikeston, MO, staffed 07:00-19:30 daily. Contractor begins delivery of rock for Dutchtown emergency levee.	East Prairie public meeting; Rep. Emerson (MO-8), Sen. Blunt (MO), Sen. McCaskill (MO) sent letter to president looking for alternative
28-Apr	Cairo stage: 58.7 (forecast crest 60.5 on 5/1). St. Francis, Ark. stage: 26.8 Memphis stage exceeds 37	Memphis, and West Memphis areas entered Phase I activities. M/V Miss. continues to hold at Hickman. All 46 access wells located and uncovered. MVM requested and received additional $740k of 210 funds. Major sand boil showed up west of the Cairo water plant and 500' from the floodwall. Operations to ring it went on through the night. 40-man construction crew delivered 4000+ cy of fill to construct ring. Appears to be piping less material and under control.	Mayor urging people to evacuate Cairo. State of MO presents request for Temporary Restraining Order (TRO) before US District Court Judge. Dyer Co. (TN) Little Levee artificially breeched after board approves action, with MVM concurrence. Private levee inside BPNM overtopped.
29-Apr	Cairo stage: 59.0 (forecast crest 60.5 on 5/1) Memphis stage: 38.4 St. Francis, Ark. stage: 26.8 Helena stage exceeds 46 Des Arc stage exceeds 25	Memphis and West Memphis areas entered Phase II activities, Clarksdale, Helena and White River areas entered Phase I. The Engineer Research & Development Center explosives team and MVM pump crew on site and awaiting further instructions. MVM Commander holds news conference at BPNM—all prepared but still holding. MVM requested and received an additional $650k of 210 funds. MVM requested and received an additional $90k of 240 funds. Numerous sizeable sand boils at Fulton Co. (Sys. 3, Seg. 11). Sheep's Ridge spur levee (Tiptonville, TN) breeches, 75' gap, 5.5' initial head differential.	US District Court Judge denies TRO. MO appeals to 8th Circuit Court of Appeals. MO NG arrives in Caruthersville to monitor floodwall. 108 USGS on site in support of Floodway operation; sheriff, state police, NG, and private security in place. USGS place sensors in Floodway. Benyaurd and quarter boats arrive.
30-Apr	Cairo stage: 59.1 (forecast crest 60.5 on 5/3) St. Francis, Ark. stage: 26.4 Memphis stage: 38.4 Helena stage: 46.6 Des Arc stage: 25.1 Front stationary along Ohio and Ark rivers 4/30-5/2. 5 day QPF 3.5-7.5"from Helena-Chester.	MVM engineering assessment to MVD Commander; 3rd large boil at Cairo and more at Fulton Concerns about stress, advising evacuation of Cairo. MVM Commander recommends move to H-21 (move barges to levee). MVD Commander orders movement to H-24 (move barges to Wickliffe from Hickman). M/V Miss. arrives Wickliffe 22:00. Street collapse on Commercial Ave between 11th and 12th Streets is still expanding with the street closed off completely. Two large sand boils were found in the bottom of one of the holes. A load of sand bags was dumped into the hole downstream of the sand boils. Backwater in BPNM floodway over MO Hwy. 80.	8th Circuit Court denies State of MO TRO appeal. Evacuation of floodway completed. City of Cairo issues mandatory evacuation.

Table IV-2. Chronology of Flood Fight Activities – Memphis District

Date	River Events	MVM Events	Other Events
1-May	Cairo stage: 59.7 (forecast crest of 61.5 on 5/5) St. Francis, Ark. stage: 26.0 Memphis stage:40.9 Helena stage: 48.03 St., Francis, Ark. stage: 26.0 Lake City stage exceeds 12 Des Arc stage:29.9 Stage at Cairo surpasses previous record of 59.51 at 02:00. 3-5"over Ohio next 24 hours. Bill Frederick reports that Cairo will surpass 60 in about 4 hours. NWS concerned localized	White River area enter Phase II, Lower St. Francis area enters Phase I. MVD Commander directs loading of pipes at 1630. Severe thunderstorms and lightning delay loading. Press conference at BPNM with Gov. of MO at 1900. Contractor began operation to supply material for the water berm near Fulton County Levee Mile 7. Seepage reported in Caruthersville, but no pin/sand boils.	Supreme Court denies request by State of MO to hear TRO. Memphis – Shelby Co. Airport Authority constructs 3-5' high temporary berm on 2nd St. to protect Dewitt Spain Airport.
2-May	Cairo stage: 61.0 at 07:00 (forecast 63.5 on 5/5). Cairo stage: 61.6 at 19:00 Cairo stage: crest of 61.72 at 22:00. BPNM Floodway operated. Cairo stage: 61.3 at 23:00, 0.4 foot stage drop despite rising river in other locations. Memphis stage: 42.1 Helena stage: 49.3 St. Francis, Ark. stage: 26.9 Lake City stage: 13.5 Des Arc stage: 33.5 2-4" last night, additional 2-2.5 forecasted today.	Helena, Clarksdale, and Lower St. Francis areas enter Phase II. Closely Monitoring the Commerce to Birds Point Levee for rising water levels. Len Small private levee is placing additional stress on the Commerce to BP levee. Received word that the Len Small levee has overtopped and possibly has been breached. Weather breaks; crews begin loading pipes at 07:20. MVM Commander briefs Walsh on Upper St. Francis overtopping potential, Fulton Co water berm, and Caruthersville overtopping potential. MVD Commander announces decision to operate Floodway at 18:30 press conference. BPNM artificially crevassed at 22:00 CDT. Frederick delivers new NWS forecast 60.5 on 5/3, 60.0, 59.9, 59.7, 59.4 on 5/7 (Deborah Lee (LRD) later reports that Cairo gage would have hit 66.73 without BPNM and KY/B ops and 65.5 without KY/B only, Banks reports that Commerce levee would have overtopped without BPNM and KY/B operation. Fuse plug levee begins overtopping at 07:00. MVM requested and received an additional $30k of 210 funds.	Blunt, Emerson and McCaskill send letter to McHugh and Grisoli asking the Corps to put the levee back as soon as possible if the BPNM floodway is operated. MVS commander reports that rock berm overtopped at emergency spillway at Wappapello. MG Peabody reports Ohio River situation deteriorating at Smithland and Paducah; Smithland mayor ordered evacuation; Patoka reservoir reaching spillway crest. Len Small Levee (IL) overtopped, breeched. Presidential disaster declaration DR-1975 for AR flooding (Craighead Co. not declared). Powers Island Private Levee (MO) breached.
3-May	Cairo stage: 60.5 Memphis stage: 43.5 Helena stage: 50.7 St. Francis, Ark. stage: crest at 27.25 Lake City stage: crest record 14.37 Des Arc stage: 35.8 Floodway operation inflow of 404,000 cfs reported (maximum); outflow 130,000 cfs)	MVM reports Cairo boils under control, Fulton Co water berm 3/4 complete. Inflow/outflow #2 near New Madrid opened at 12:37.	Barnett reports 25 landowners have filed suit against the Corps for taking of land

Table IV-2. Chronology of Flood Fight Activities – Memphis District

Date	River Events	MVM Events	Other Events
4-May	Cairo stage: 59.8 (original forecast prior to opening was 62.8 this a.m.) Memphis stage: 44.3 Helena stage: 51.8 St. Francis, Ark. stage: 27.2 Lake City stage: 14.1	MVM Commander reports 400 kcfs going into floodway; 17 kcfs out through #2 and 113kfcs thru gap.	Presidential disaster declaration DR-1976 for KY flooding. MO NG constructed rock dike to prevent overflow water from Ditch 81 from inundating homes near Hornerville, MO.
5-May	Cairo stage: 59.6 (river would have crested at 63.0 this morning without BPNM operation) Memphis stage: 45.1 Helena stage: 51.6 St. Francis, Ark. stage: 27.2 Lake City stage:13.7 Des Arc stage: 38.4	Tiptonville and Caruthersville 1 foot of freeboard, building 3' high setback levee at Caruthersville and pump to combat concerns about wave wash and overtopping. MO NG proposal to increase wall height was evaluated and deemed unsafe. Fulton Co. water berm complete and working as designed; Cairo boils in stabilized condition. Inflow/outflow #1 opened using alternative explosive agent at 14:35. Contractor placed gravel to raise low spots of St. Francis levee south of Lake City. Contractor delivered 1,000 tons of gravel to raise White River levee near Biscoe, AR 18". New slide reported on riverside of setback levee (Sys. 2, Seg. 9) Levee Mile 12/42+50. Numerous small sand boils noted at Ensley Levee in Memphis (Sys.7, Seg. 24).	Due to freeboard issues at Caruthersville, CG to close Miss R. to navigation at 1200 on 5/6 near Caruthersville for 8 days. (Closure deferred until stages reach 48.0 on Caruthersville gage; river crested at 47.61 on 5/7). AR DOT closed I-40 at White River due to high water. Temporary berm constructed by Memphis–Shelby Co. Airport Authority on 2nd St. breeched after water mail broke under berm; Dewitt Spain Airport flooded.
6-May	Cairo stage: 59.4 New Madrid stage: record crest of 48.35 Memphis stage: 45.6 Helena stage: 53.6 St. Francis, Ark. stage: 27.0 Lake City stage: 13.5 Des Arc stage: 39.2	MVM ends Phase II flood fight in Lower St. Francis area. Contractors continued delivery of materials to raise low spots in the TN levee near Tiptonville (Sys. 3, Seg. 13). West Memphis team reports two large sand boils, numerous pin boils, and small slides at Levee Mile 198 (Sys. 2, Seg. 17). White River overtops Sys. 15, Seg. 51 north of Biscoe, AR, flooding agricultural land.	
7-May	Cairo stage: 59.0 Caruthersville stage: record crest of 47.61 Memphis stage: 46.8 Helena stage: 54.5 St. Francis, Ark. stage: 26.7 Des Arc stage: record crest of 39.43 Lake City stage: 13.4		
8-May	Cairo stage: 58.7 Caruthersville stage: 47.4 Memphis stage: 45.5 Helena stage: 55.2 St. Francis, Ark. stage: 26.1 Des Arc stage: 38.9 Lake City stage: 13.2	MVM Commander reports that Memphis flooding on news is backwater flooding from Wolf and Loosahatchie rivers. MVM requested and received an additional $600k of 210 funds. Floodway inflow matching outflow indicating that volume is starting to tip toward outflow.	

Table IV-2. Chronology of Flood Fight Activities – Memphis District

Date	River Events	MVM Events	Other Events
9-May	Cairo stage: 58.3 Memphis stage: 47.8 Helena stage: 55.9 St. Francis, Ark. stage: 25.5 Des Arc stage: 38.0 Lake City stage: 13.0	White River no longer overtopping Sys. 15, Seg. 51 near Biscoe, AR.	Presidential disaster declaration DR-1979 for TN flooding. Presidential disaster declaration DR-1980 for MO flooding. AR DOT reopens eastbound lanes of I-40 at White River after it was closed because of high water.
10-May	Cairo stage: 57.8 Memphis stage: crest of 48.03 Helena stage: 56.2 Des Arc stage: 36.9 St. Francis, Ark. stage: 25.1 Lake City stage: 12.6	MVM ends Phase II flood fight in Upper St. Francis.	
11-May	Cairo stage: 57.3 Memphis stage: 47.6 Helena stage: 56.4 Des Arc stage: 35.7 St. Francis stage drops below 24 Lake City stage drops below 12	24-hour levee patrols end in Cairo, MO and Reelfoot-Obion areas. MVM ends Phase I flood fight in Lower St. Francis area. Dutchtown, MO emergency levee removed.	Presidential disaster declaration DR-1983 for MS flooding. AR DOT reopens all lanes of I-40 at White River after it was closed because of high water.
12-May	Cairo stage: 56.7 Helena stage: crest at 56.59 Des Arc stage: 34.7 St. Francis stage: 24.5	Crest has passed MVM and river is now in a steady fall. System still under a lot of stress. EOC lowers activation to Level III (12-hour operations).	
13-May	Cairo stage: 56.0. Helena stage: 56.5 Des Arc stage: 33.7 St. Francis stage: 24.2	New sand boils discovered piping material near Mound City, IL (Sys. 1, Seg 2). Sand boils continue to develop in Caruthersville, MO.	
14-May	Cairo stage: 55.2 Helena stage:56.4 Des Arc stage: 32.8 St. Francis stage: 24.4	Sand boils continue to develop Levee Mile 90-92 of Sys. 8, Seg. 26 (Rena Lara area). Levee District constructed several water berms after ringing with sandbags failed to contain the boils.	
15-May	Cairo stage: 54.4 Helena stage: 55.9 Des Arc stage: 31.9 St. Francis stage: 24.2	Sand boils continue to develop behind Ensley Levee (Sys. 7, Seg. 24).	MODOT closes right northbound and southbound lanes of I-55 miles 58-60 because of backwater from St. Johns Bayou over the road.
16-May	Des Arc stage: 31.0 St. Francis stage drops below 24	MVM ends Phase I flood fight in Upper St. Francis area.	
17-May	Des Arc stage: 30.1		
18-May	Cairo stage drops below 52 Clarendon gage (White River) drops below 35	MVM ends Phase II flood fight in Cairo, MO, Reelfoot-Obion, and White River areas.	

Table IV-2. Chronology of Flood Fight Activities – Memphis District

Date	River Events	MVM Events	Other Events
19-May	Cairo stage: 51.3		St. John's gates open at 02:00.
21-May	Cairo stage drops below 49 Memphis: 40.3 Helena: 52.2	MVM ends Phase I flood fight in Cairo, MO and Reelfoot-Obion areas.	
22-May	Memphis: 39.1 Helena: 51.4	MVM ends Phase II flood fight in Memphis and West Memphis areas.	
24-May	Memphis stage drops below 37	MVM ends Phase I flood fight in Memphis and West Memphis areas.	
26-May	Helena stage drops below 48	MVM ends Phase II flood fight in Helena and Clarksdale areas. MVM requested and received an additional $520k of 210 funds.	
28-May	Helena stage drops below 46	MVM ends Phase I flood fight in Helena and Clarksdale. EOC ends Level III activation, returns to Level I.	
29-May	Des Arc: 27.8	All gages below flood stage or falling with no issues.	
2-Jun	Cairo stage: 46.0	Water stops flowing into the Floodway inflow crevasse.	
5-Jun	Des Arc stage: 28.1	MVM ends Phase I flood fight monitoring in White River area, deactivates EOC.	
7-Jun	Cairo stage drops below flood stage (40)		Presidential disaster declaration DR-1991 for IL flooding.
23-Jun	Cairo stage: 39.8	MVM completes construction of emergency berm at BPNM center crevasse to EL 301.0 to prevent rising river from reentering Floodway.	
24-Jun	Cairo stage exceeds flood stage (40)		
30-Jun	Cairo crests at 41.94 Helena stage drops below flood stage (44)	Emergency berm prevents water from reentering Floodway	
3-Jul	Cairo stage drops below flood stage (40) for last time until 12/2/11		

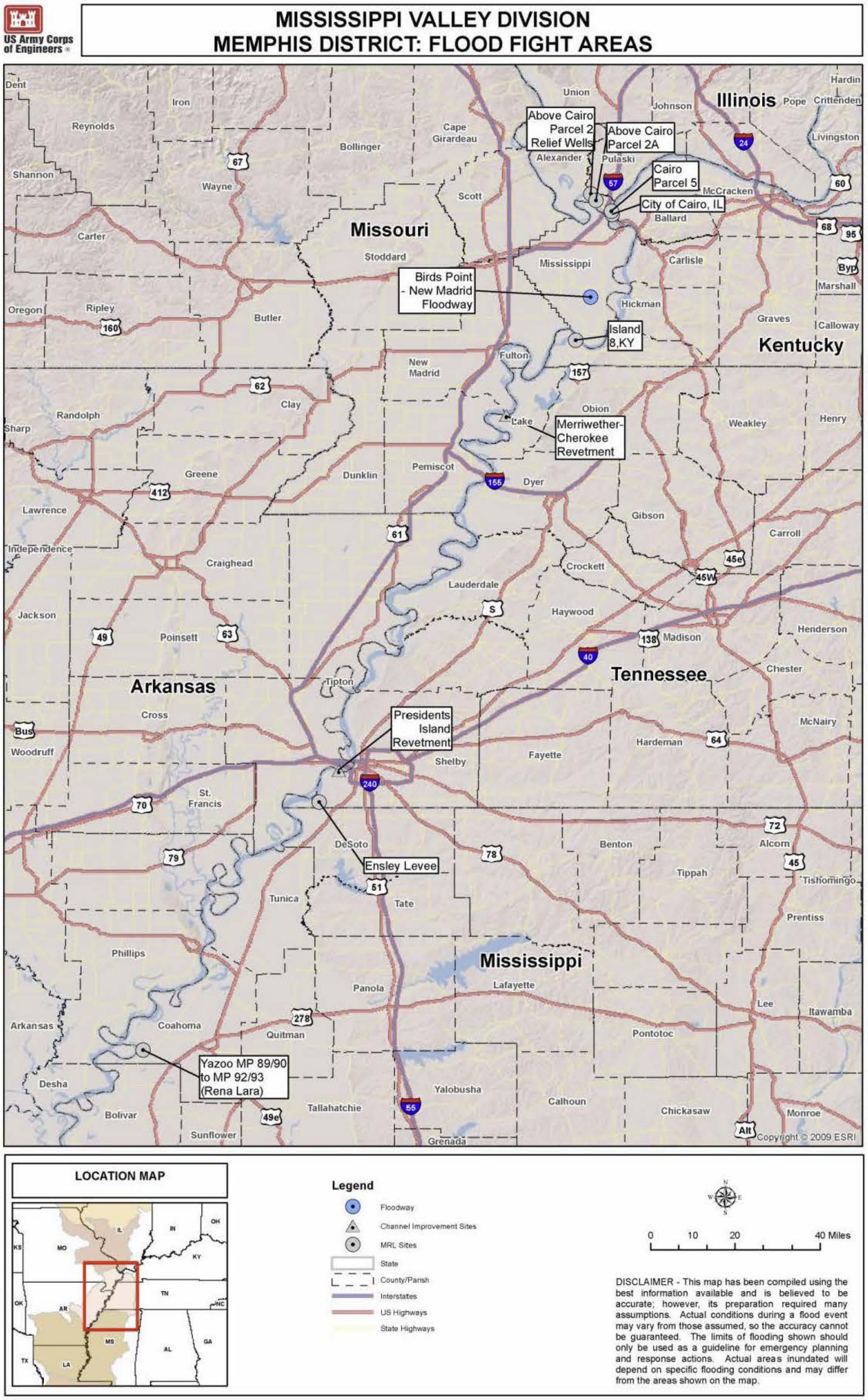


Figure IV-1. Key Flood Fight Locations in the Memphis District

d. Key Flood Fight Locations

i. City of Cairo, IL. Known seepage issues existed in Cairo (figure IV-1) near System #1, Segment #3, levee mile 8/30+48 [(Ohio River, right descending bank (RDB)]. During the 2011 Flood, major seepage in the form of three high energy sand boils with sand cones from 8 to 15 feet in height occurred in this area. Major flood fighting efforts were required starting at approximate river stage reading of 52.3 feet (10-year event) and higher. A history of repeated very large, high energy sand boils were recorded in this area starting at river stages of 54 feet in 1995, 1997, 2002 and 2011. Throughout the flood fight, issues were noted with the city being unable to operate pumping stations due to poor maintenance. This resulted in localized flooding due to impounded rainwater near the inoperable pumps.

ii. Cairo, IL, Parcel 5. During the 2011 event, major seepage was observed near Mound City and Cairo near System #1, Segment #2 (Ohio River, RDB) in the form of multiple large, high energy sand boils in the sump area of the Goose Pond Pumping Station. Historically, a great number of sand boils have been observed here starting at river stages of 52 feet during high water events exceeding the 10-year event. Considering the number and size of the sand boils, the only means of fighting the uncontrolled seepage in this area is to increase the depth of water within the sump area of the Goose Pond pumping station and flood adjacent lands. During the 2011 event, this strategy resulted in some flooding of adjacent neighborhoods.

iii. Above Cairo, IL, Parcel 2A. Major seepage was observed near Future City and Cairo near System #1, Segment #5 [(Mississippi River, left descending bank (LDB)] in the form of hundreds of small to medium sand boils during the 2011 Flood. Most of these boils had throat diameters of greater than 4 inches and cone diameters of 3 to 6 feet or greater. During the 2011 event, significant flood fighting was required starting at an approximate river stage of 52.3 feet (10-year event) and higher. A history of hundreds of medium to large sand boils within 50 feet of the toe of the levee are recorded for every event exceeding the 10-year event. Considering the number and size of the sand boils, the only means of flood fighting the uncontrolled seepage in this area is to establish the necessary height of water within the ditches and culverts near Highway 3. Only a relatively low head can be maintained however, without flooding the highway.

iv. Fulton Co., KY, Island 8. Seepage was observed in System #3, Segment #11 from levee mile 1/0+00 to 15/0+00 near Island 8 (Mississippi River, LDB) during the 2011 event. From mile 5/35+00 to mile 15/0+00, the majority of the area had heavy seepage with pin boils and small boils with at least 3 areas having large to large high energy boils. This area required significant flood fight efforts to ensure and maintain the integrity of the levee. Multiple large to very large high-energy sand boils approximately 100 feet from levee toe and three large sand boils at the levee toe were flood fought in mile 5. A rock dike was installed and the area was flooded (water berm) to control seepage here when the stage exceeded 59 feet.

v. Birds Point New Madrid Floodway. The Floodway was operated for only the second time in its existence in 2011. The inflow at Birds Point was artificially crevassed May 2 at 22:00, at a stage of 61.72 feet. Inflow/Outflow #2 near New Madrid was artificially crevassed May 3 at 12:37, and inflow/outflow #1 near Seven Island Conservation Area was artificially crevassed May 5 at 14:35 (all times CDT). Operation lowered the stage at Cairo by 0.5 foot in the first hour, and lowered the expected crest by 3.5 feet. Maximum flow through the Floodway was 403,000 cfs. Water ceased entering the inflow crevasse June 3, 30 days after operation. A temporary berm was constructed in June to prevent water from reentering the Floodway. A detailed description and timeline for the operation of the floodway is provided in Section IV.E of this report.

vi. President's Island, Memphis, TN. Bank failure and scour occurred at about RM 732 (LDB) where the river attempted to straighten the bend at President’s Island. Top bank scour was 2,500 feet wide and 20 to 25 feet deep. Overbank scour was approximately 50 feet deep and extended inland approximately 3,000 to 3,500 feet.

vii. Sheep's Ridge Road / Meriwether-Cherokee Revetment, Tiptonville, TN. Bank failure and breach of spur levee occurred at about RM 869 (LDB) where the river attempted to straighten a bend. Top bank scour was approximately 2,200 feet wide and 50 to 60 feet deep. Overbank scour was approximately 80 feet deep and extended inland for 3,000 to 4,000 feet.

viii. Rena Lara, MS. Seepage was observed in System #8, Segment #26 from levee mile 89/34+70 to 90/0+00 (Mississippi River, LDB). Numerous small to medium size boils developed in the area. Several water berms were constructed to control seepage.

ix. Ensley Levee, Memphis, TN. Major seepage was observed in South Memphis in System #7, Segment #24 (Mississippi River, LDB), in the form of numerous small to medium size sand boils. Some of the boils had throat diameters of greater than 4 inches and cone diameters of 3 to 6 feet or greater. Significant flood fighting effort was required when river stage readings were 45 feet and higher. The most active area was near Levee Mile (LM) 9.1-9.4. Small to medium boils developed there when stages reached 45 feet and continued to grow even after the crest. Boils stopped piping material when the river dropped below 44 feet, but were still flowing clear when Phase I monitoring ended at 37 feet. The boils developed near the toe of the seepage berm. More than 22 boils were ringed in the vicinity. To mitigate the sand boils, the City of Memphis ceased operations at the Ensley Pumping Station (LM 12) per a request from MVM between May 5 (stage exceeding 45 feet) and May 20 (stage below 40 feet). Smaller pin boils developed at LMs 2.8 and 11.1 to 11.6 after the river crested.

3. Vicksburg District

a. Flood Fight Summary. The MVK Commander signed a Declaration of Emergency at 0700 hours on 25 April 2011 due to a significant flood threat on the Mississippi River, initiating Phase I of MVK's Emergency Response Plan. The MVK Emergency Operations Center (EOC) was activated at Level I on 25 April 2011 and at Level II on 30 April 2011 in response to the rising water levels along the Mississippi River. Phase II of the flood fight began on 4 May 2011 when the Mississippi River rose to over 44 feet on the Arkansas City gage. Phase II 24-hour levee patrols began on 7 May 2011 in all sectors and continued until 12 June 2011. The MVK EOC began Level III 24-hour operations on 8 May 2011 and remained so until 4 June 2011. The MVK EOC returned to normal operations on 20 June 2011. Flood fight operations in the MVK required 238 Corps personnel. 1,415,000 sandbags were issued, and 11,110 linear feet of HESCO bastions were used to execute flood fight efforts.

The MVK EOC developed many new processes and changes to existing processes during the 2011 Flood:

- Area Action Officer (AAO) positions were established. The AAOs acted as liaisons between the EOC and their respective area offices, providing one point of contact between the two.
- A Project Manager was used to create and implement a system to make personnel requests more formal and efficient, and to revise the organization chart specifically for this event.
- The FreeBoard database system was used by the MVK for this event. This system was used to report and track inspection points along the levee systems, and also to track flood fight supplies and equipment.
- The EOC used a dedicated GIS specialist throughout the event in order to coordinate all mapping and imagery products.
- The EOC implemented a new report called the Hot Spot Brief, which was updated daily and provided to the District Commander. The report detailed the current status of all significant projects and incidents within the District.

A further challenge posed during this event was the simultaneous FEMA mission regarding debris removal and demolition related to a severe storm and tornados that produced extensive damage across Mississippi on

27 April, most notably in Smithville, MS and Monroe County. This mission called for a total of 38,500 tons of debris to be removed and a total of 2,900 tons of demolition debris. The MVK EOC was engaged in both the flood fight and in the tornado mission throughout the duration of the flood fight.

The MVK EOC was also involved in a flood fight effort along the Coldwater River near Marks, MS due to a significant rainfall event 24-28 April over the upper portion of the Yazoo Basin. The Coldwater River basin received most of this precipitation, with 12 to 15 inches falling over the entire watershed and Arkabutla Dam receiving 15.16 inches of rain. The Coldwater River rose to near record stages in Sarah, Birdie, Darling, and Marks, MS and crested at Marks on 2 May. The gates at Arkabutla Dam remained closed during this event, and water flowed over the spillway producing approximately 250 cfs flow on 13-29 May. Greenwood Area Office was engaged with this flood fight during the beginning stages of the flood fight along the Mississippi River and Yazoo River Backwater. The Marks Sector Commander began coordinating flood response efforts with local officials in Marks on 27 April. City officials requested sandbags and technical assistance regarding inspection of levees and improvements to a portion of the levee that protects the City.

The MVK established a Rapid Response Team during this event to plan for and respond to levee breaches and other failures of the levee system. The Team used breach inundation maps for seven locations throughout Louisiana and Arkansas to plan for response to a levee breach, based on locations with the highest potential for breach or the highest potential for damage to critical infrastructure in the event of a breach. Those locations were Vidalia, LA; Kings Point, LA; Tallulah, LA; Lake Providence, LA; Waterproof, LA; Transylvania, LA, and Willow Lake, AR.

A Rapid Response Team was created and split internally into two teams that planned for and would respond to events north and south of Vicksburg, MS. The team coordinated with sector leads and county / parish leaders to develop an action plan and to determine capabilities such as manpower, equipment, and supplies. Coordination included preparing legal documents such as ROE forms and lease agreements that could be put into effect quickly. Coordination was also made with the Louisiana National Guard to determine its capabilities and to plan for air support if required. The team collected information regarding the location of equipment and supplies available to the District, but did not pre-stage any equipment or supplies except for the Engineer Research and Development Center (ERDC) PLUG, which is an emergency breach repair consisting of a fabric tube that inflates in place.

Geotechnical Branch created High Water Inspection Teams to conduct a high water inspection of the levees during this event. Three teams of three geotechnical engineers traveled downriver on foot and using UTVs following the crest and capturing all of the data they could in order to document seepage performance along the length of the levees. This information will be consolidated and used for future designs and to document the actual performance of the levees. Preparatory projects consisted of providing protection at known hot spots and addressing any known deficient areas of the system. There were three main efforts in preparing for this flood: the Buck Chute hot spot; protection and repair along the Yazoo Backwater Levee; and protection and repair near Vidalia, LA.

b. Funding Details

3112 MR&T Appropriation Direct	$10,172,729
3125 FCCE Reprogrammed from MR&T	$3,470,422
3125 FCCE Emergency Operations	$1,350,000
Total Flood Fight	**$14,993,151**

c. Chronology of Flood Fight Activities. Table IV-3 on pages IV-16 through IV-18 shows the chronology of flood fight activities in the Vicksburg District. All times are CDT.

Table IV-3. Chronology of Flood Fight Activities – Vicksburg District

Date	River Events	MVK Events	Other Events
25-Apr	Predicted crest at Vicksburg: 52.5	Declaration of Emergency signed by COL Jeffrey Eckstein	
	Steele Bayou control structure closed	EOC activated at Level I, duty hours 0730 – 1600 MVK requested and received $25k of 210 funds	
26-Apr	Predicted Crests updated: Arkansas City - 48.5 / 14 May Greenville - 60.0 / 15 May Vicksburg - 53.5 / 18 May Natchez - 60.0 / 20 May		
27-Apr	MVK requests permission to deviate from the water control plan at Muddy Bayou in order to raise the water level at Eagle Lake		
29-Apr	Mississippi River entered Phase I at Arkansas City and Greenville gages	MVK requested and received $225k of 210 funds	MVK begins installing stoplogs at the floodwall
		MVK received request from Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP) to evaluate possible flood protection options for the Vidalia Convention Center	
30-Apr	Muddy Bayou control structure opened to let water into Eagle Lake	EOC activated at Level II, duty hours 0700 - 1930	
1-May	Mississippi River entered Phase I at Vicksburg and Natchez gages		
2-May	Crests revised upwards significantly Arkansas City - 53.5 / 14 May / +5.0 Greenville - 64.5 / 15 May / +4.5 Vicksburg - 57.5 / 18 May / +4.0 Natchez - 65.0 / 20 May / +5.0	Phase I levee patrols begin at all sectors	SR 465 to Eagle Lake closes
	Coldwater river crests at 41.0 ft in Marks	Marks sector begins Phase I response in upper Yazoo R. Basin	
3-May			BPNM Floodway operated
4-May	Mississippi River entered Phase II at Arkansas City and Greenville gages		President declares disaster: 14 counties in MS declared for public assistance
	Crest dates revised Arkansas City - 16 May / +2 days Greenville - 17 May / +2 days Vicksburg - 20 May / +2 days Natchez - 22 May / +2 days		
5-May	Natchez crest gage revised - 64.0 / 22 May / -1.0		
6-May	Mississippi River entered Phase II at Vicksburg and Natchez gages	MVK requested and received $600k of 210 funds	President declares disaster: 26 parishes in LA declared for public assistance (9 are in the MVK AOR)
		Stabilization work at Buck Chute complete	

Table IV-3. Chronology of Flood Fight Activities – Vicksburg District

Date	River Events	MVK Events	Other Events
7-May	Anticipated overtopping of abandoned levee occurs near Grand Lake, AR	Phase II (24 hr) levee patrols begin at all sectors	
		MVK requested and received $600k of 210 funds	
		MVD receives FEMA Mission Assignment (Verbal) COE-MVD-01 for 3322-EM-LA – Regional Activation funded at $50,000	
		MVD receives FEMA Mission Assignment (Verbal) COE-MVD-01 for 3320EM-MS – Regional Activation funded at $10,000	
8-May		MVK EOC begins 24-hr operations	Vicksburg completes closure of floodwall
		ECCV 5 arrives in the MVK AO, stationed at the Yazoo River bridge on US 61N	
9-May	Crest dates revised Arkansas City - 15 May / -1 day Greenville - 16 May / -1 day Vicksburg - 19 May / -1 day Natchez - 21 May / -1 day		Bonnet Carré Spillway opened
10-May		Significant sand boil identified in the Rosedale sector	
11-May	Greenville crest gage revised - 65.0 / 16 May / +0.5	ECCV 5 moved to Lake Chicot Pumping Plant to support SEAPO	Presidential disaster declaration: 14 counties in MS declared for individual assistance
		MVK receives funding increase for FEMA Mission Assignment (Verbal) COE-MVD-01 for 3320EM-MS of $10,000 to $20,000	
12-May	Anticipated overtopping of abandoned levee occurs near Wilson Point, LA		US 61 south of Vicksburg, SR 16, and SR 149 close
			N. Washington Street is inundated
13-May	Water begins flowing over spillway at Arkabutla Dam, approx. 250 cfs	Erosion protection for landside of Yazoo Backwater Levee complete	US 61N north of Vicksburg closes
14-May	0.5 foot drop at the Greenville gage determined to be from crevasse at Wilson Point abandoned levee overtopping	All levee raises in the Yazoo Backwater Levee and near Vidalia are complete	Morganza Control Structure opened
	Greenville / Natchez crests revised Greenville - 64.8 / 16 May / -0.2 Natchez - 63.5 / 21 May / -0.5		
15-May	Greenville crest gage revised - 64.5 / 17 May / -0.3		HESCO failure at the Vidalia Convention Center due to pipe seepage
16-May	Mississippi River crests at Arkansas City, gage reading 53.14	MVK requested and received $500k of 210 funds	
	Natchez crest gage revised - 63.0 / 21 May / -0.5	Natchez requests assistance with erosion protection at Silver St.	

Table IV-3. Chronology of Flood Fight Activities – Vicksburg District

Date	River Events	MVK Events	Other Events
17-May	Mississippi River crests at Greenville, gage reading 64.22	Sand boil and levee slide identified in Mayersville Sector near Station 8170+00 (Albermarle)	Yazoo Backwater Levee is closed to all vehicle traffic
18-May	Vicksburg / Natchez crests revised Vicksburg - 57.1 / 19 may / -0.4 Natchez - 62.5 / 21 May / -0.5		
19-May	Mississippi River crests at Vicksburg, gage reading 57.1	Erosion protection at Silver St. Natchez complete	
	Mississippi River crests at Natchez, gage reading 61.95		
20-May		Android devices are fielded to Vidalia Area Office	
23-May		MVK receives FEMA Mission Assignment COE-MVD-02 for 1983DR-MS – Regional Activation funded at $40,000	
25-May		Work completed on Albermarle levee slide	
29-May		Significant sand boil found in St. Joseph sector near levee station 6185+75	
1-Jun	Mississippi River gage at Arkansas City falls below Phase II		US 49W, US 61/SR 3 north of Vicksburg and SR 16/SR149 open
3-Jun	Mississippi River gage at Greenville falls below Phase II	SEAPO ceases 24 hr levee patrols	US 61 south of Vicksburg opens
4-Jun		MVK EOC ceases 24 hr operations, reducing to 12 hr operations	Vicksburg begins removal of stoplogs in the floodwall
6-Jun		MVK receives funding increase for FEMA Mission Assignment COE-MVD-02 of $18,000 to $58,000	
8-Jun	Mississippi River gage at Vicksburg falls below Phase II	GAO ceases 24 hr levee patrols	
12-Jun		VAO ceases 24 hr levee patrols	
15-Jun	Mississippi River gage at Natchez falls below Phase II		
17-Jun		All 21M class funds revoked from MVK; total is $529,577.97	
18-Jun	Steele Bayou control structure opens		
20-Jun	Muddy Bayou control structure opened to let water out of Eagle Lake	Final MVK SITREP for this event submitted	

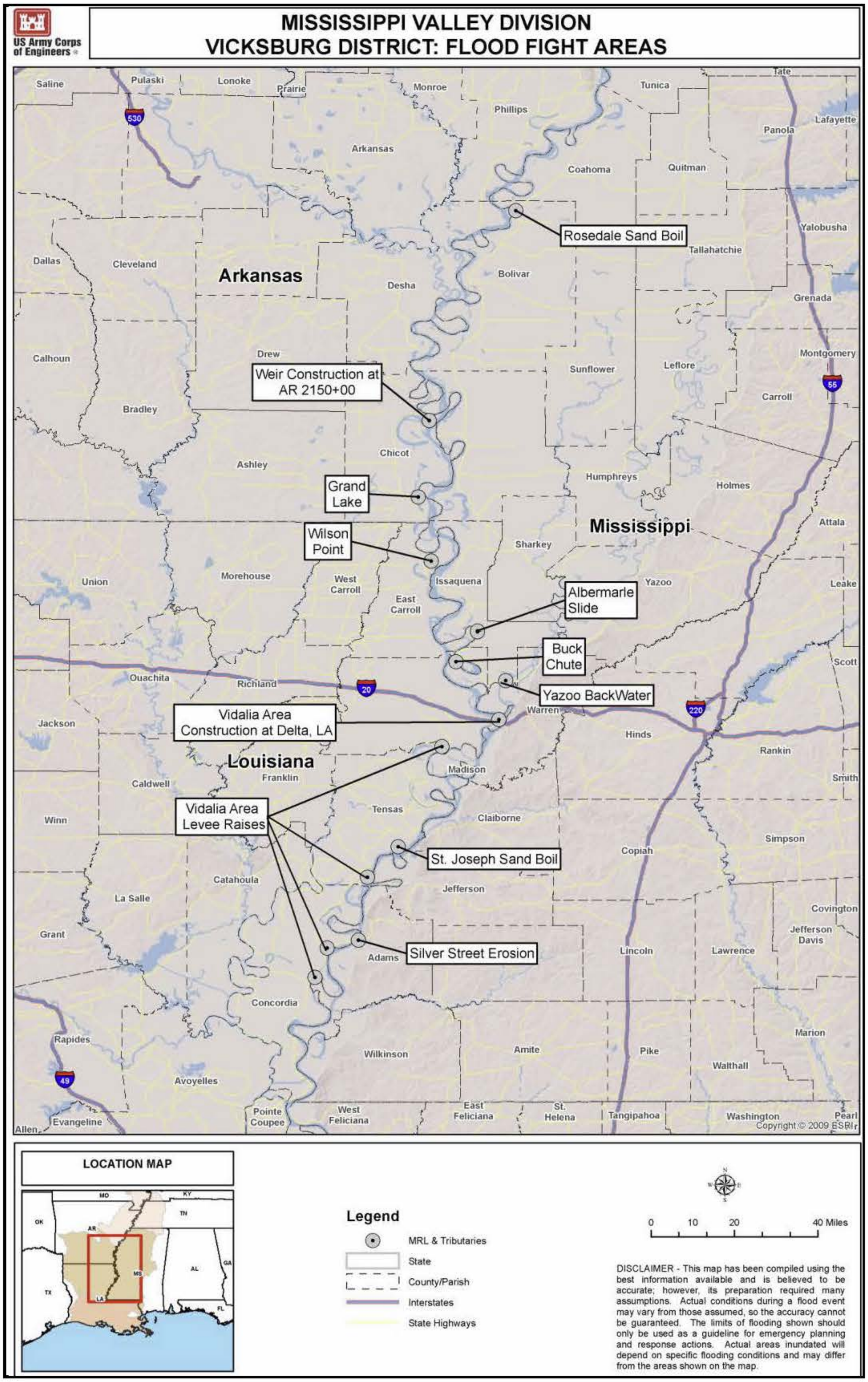


Figure IV-2. Key Flood Fight Locations in the Vicksburg District

d. Key Flood Fight Locations

i. Buck Chute. In February 2010, the MVK was notified of boils that occurred in an area along the berm toe north of Buck Chute, near Eagle Lake, MS (figure IV-2). The District began designing a repair for this area in the summer of 2010 based on that notification and on experience gained during the 2008 flood. By the time the Flood occurred, a stabilization berm was already scheduled to be constructed in the fall of 2011 at the location where sand boils were prevalent.

MVK addressed this known hot spot using two methods: constructing an emergency stabilization berm (using a different design from the final design discussed above) in the area where boils had been identified in 2010, and raising the water level at Eagle Lake to lower the hydraulic head. The improved stabilization at Buck Chute included clearing the area around the boils, constructing a dike around the boils to enclose approximately 2 acres, filling the enclosed area with sand, and providing a clay cap. This berm was intended to control seepage pressures on the land side of the levee and prevent the transport of materials under the levee system. Construction was completed by hired labor on 6 May 2011.

In addition to supplying contracts for gravel and other materials, an emergency contract was issued to transport approximately 25,000 cubic yards (CY) of sand from the Mat Casting Field at Delta, LA to the Buck Chute site. The Federal government took possession of this sand and quickly transported and stockpiled it at the Buck Chute site to meet the immediate need for use in the stability berm. The sand had been stockpiled at the Mat Casting Field by Fordice Construction, but mat casting work was suspended due to the approaching flood waters. The mat casting contract was later modified to replace the sand.

MVK requested and the MVD Commander approved a deviation from the established Eagle Lake water control plan on 28 April in order to raise the water level at Eagle Lake to 90.0 feet, in order to offset pressure caused by high riverside water levels. On 29 April, prior to opening the Muddy Bayou control structure in accordance with the deviation, the water level at Eagle Lake was 77.6 feet. The Muddy Bayou control structure was opened on 30 April to allow water to enter the lake, which reached a stage of 89.8 feet at crest due to lower than average rainfall across the watershed. Muddy Bayou was opened on 20 June to let water out of the lake. Due in part to these emergency operations, there were no significant issues with seepage or sand boils at Buck Chute during this high water event. However, raising the water level at Eagle Lake caused damage to piers and boat houses around the lake and impacted boating and fishing in the area.

ii. Yazoo Backwater Area Levee. The Yazoo Backwater Area is located in west central Mississippi in portions of Warren, Issaquena, Sharkey, Yazoo, Humphries, and LeFlore Counties, near the confluence of the Yazoo and Mississippi Rivers (figure IV-3). Several measures were required at the Yazoo Backwater Area Levee during this event. This flood was forecasted to overtop this levee and put the Yazoo River Backwater Area into operation for the first time since its completion, and a great amount of work went into preparing the levee for that predicted overtopping. The total cost of preparations on the Yazoo Backwater Area Levee was $1.94 million.

a. Erosion Protection. As an authorized backwater area within the MR&T system, the Yazoo River Backwater Area is designed to store floodwaters during very large floods through overtopping of the Yazoo Backwater Area Levee, which is intentionally constructed to a lower grade than the mainline Mississippi River levee. The Yazoo Backwater Area levee system consists of two segments, a 26 mile segment that is a flat 107.0 elevation (approximately 5 feet below the mainline levee grade) which serves as an outlet to allow water to enter the backwater area under PDF conditions, and the sloped Whittington Right Bank levee, which provides headwater flooding protection from the Yazoo River. In addition to the two connected levee segments, the Yazoo Backwater area has two drainage structures on the Little Sunflower

River and Steele Bayou. These levee segments and drainage structures protect approximately 1,550 square miles of land lying between the east bank Mississippi River levee and the Yazoo Backwater Levee System.

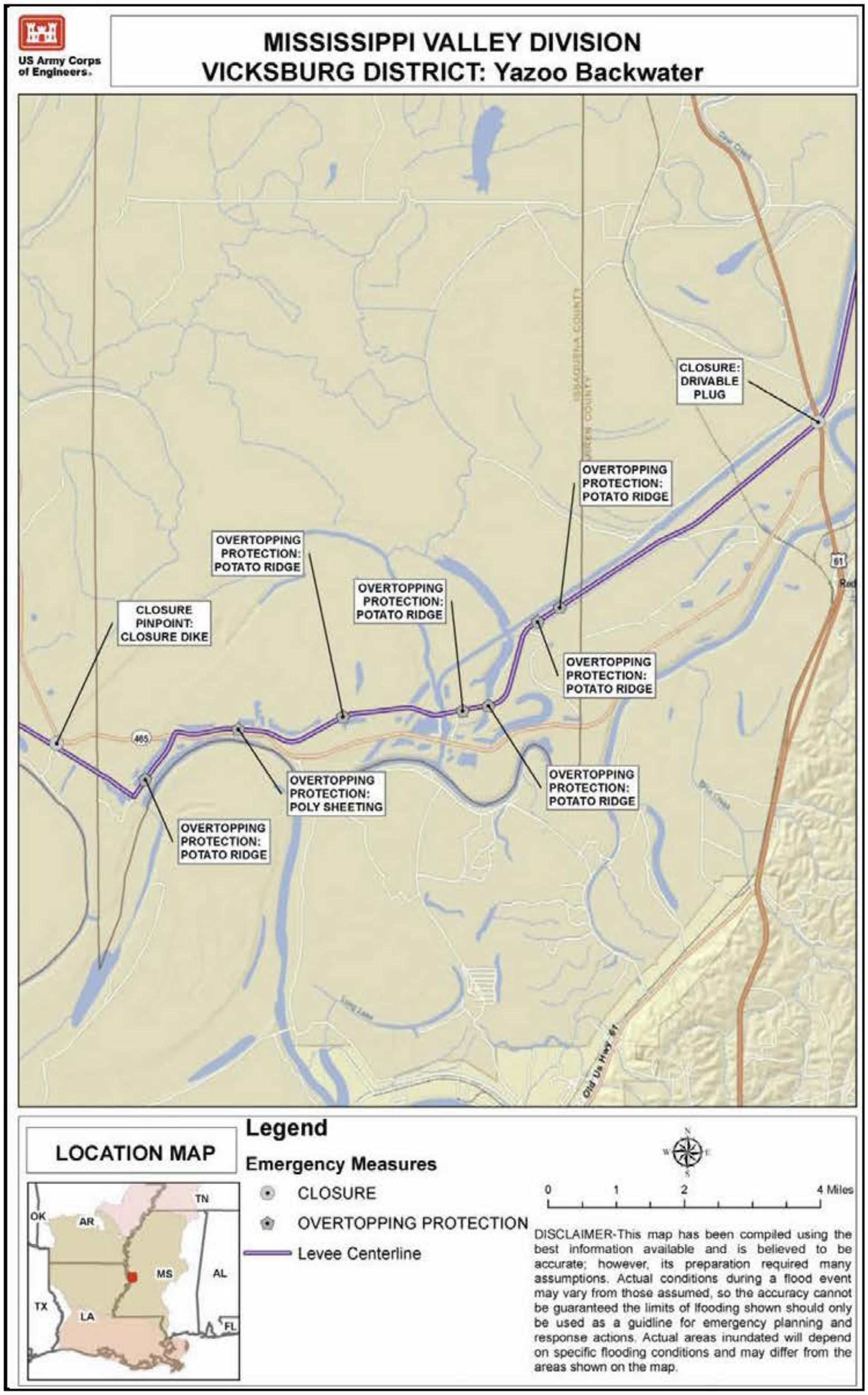


Figure IV-3. Yazoo Backwater Area

The Yazoo Backwater levee ties into the lower end of Mississippi River levee near Eagle Lake and ties to high ground near Morgan City. The area is subject to flooding from the Mississippi River backwater which can enter the area by overtopping the lower portion of the Yazoo Backwater Area levee. It can also receive flood waters from headwater flooding of the Yazoo River.

By late April, forecasts indicated that crest stages on the Mississippi River would cause elevations at the intersection of the mainline levee and the Yazoo Backwater levee (MS East Sta. 9314 + 71) to exceed 107 feet NGVD29, overtopping the levee and putting the backwater area into operation. In preparation of this event, MVK installed polyethylene sheeting for erosion protection along the land side of the levee to prevent damage to the levee slope and berm during the forecasted overtopping, mitigating the risk of catastrophic crevassing and failure of the levee while still providing for the feature's intended function. Polyethylene sheeting was placed along a 4 mile section of the Yazoo Backwater Levee land side slope starting approximately 1,700 feet from the junction of the Mississippi River Levee and the Yazoo Backwater Levee and extending approximately 4 miles to 2,700 feet west of the Steele Bayou control structure. A small trench was excavated at the land side crown and the sheeting was anchored within the trench and draped down the land side slope of the levee. Polyethylene sheeting was provided by GSE Lining Technology, Inc. for $700,000.

GSE Lining Technology also provided approximately 60 personnel to assist in installation, including special equipment and trained technicians to seal 100 percent of the seams on the fabric. Supplies, labor, equipment, and installation guidance and assistance were provided by American Environmental Group, Ltd. for $493,000. Installation of the erosion protection was accomplished by Fordice Construction for $315,000. With a potential for overtopping forecast for 15 May, the scope of work was developed on 5 and 6 May. Engineering and Construction and Contracting met with Fordice Construction on-site near the Steele Bayou structure and contracts were awarded in the early afternoon on Friday, 6 May. Work began immediately to mobilize equipment, assemble the contractor workforce, and ship materials. Fabric was delivered over a three day period and staged at the harbor for transport to the site by Fordice Construction.

Fabric installation began on the morning of Saturday, 7 May as soon as the first materials arrived in Vicksburg. Fabric was installed and seamed during daylight hours and materials were staged along the levee at night for placement the next day. The Mississippi National Guard was on alert for possible deployment to assist with this work if necessary, but was cancelled on Sunday, 8 May once the contractor's capabilities and progress were confirmed. Access along the levee was very congested during the fabric installation, and a one-way traffic plan was developed to ensure traffic flow during construction. All fabric was essentially installed by the evening of 11 May, with all work completed on 13 May.

b. Overtopping Protection. In order to direct the predicted overtopping water away from landside toe of the mainline Mississippi River Levee, protection was placed along the crown of the Yazoo Backwater Levee extending from the junction with the Mississippi River Levee east for 2,000 feet. The protection was planned to be 4 foot high Rapid Deployment Floodwall, but due to a shipping delay was changed to 4 foot HESCO bastions. The HESCOs were placed by hired labor starting on 10 May and were completely placed on 13 May.

c. Pinch Point Closure Dike. In order to prevent overtopping water from flowing north along the toe of the Mississippi River Levee, a 7 foot dike was constructed on the section of PawPaw Road between the mainline Mississippi River Levee and Highway 465. This dike consisted of approximately 2,000 CY of material borrowed from the Muddy Bayou borrow area. Construction was done by Hired Labor starting on 6 May and completing on 12 May.

d. Yazoo Backwater Levee Low Spots. Several deficient areas were identified along the Yazoo Backwater Levee, including cattle guards and portions of the levee below design grade. One site was located between the Mississippi River Levee and the Steele Bayou control structure; four sites were located between Steele Bayou and US 61. This area posed a significant traffic risk as that portion of the levee was still open to public traffic. Hired Labor placed fill and potato ridges (i.e., small earthen berms) on the levee crown starting 6 May and completing on 16 May. The Board of Mississippi Levee Commissioners also raised several low spots along the Yazoo Backwater Levee north of US 61.

e. 61N Driveable Plug. The portion of the Yazoo Backwater Levee at the intersection with US 61 was closed with a drive-able plug. This closure was designed to ensure traffic access along the levee, and also allow vehicles to enter and exit the levee from US 61. Construction was done by Hired Labor starting 13 May and completing 14 May.

Although several sections of US 61 were predicted to overtop during this event, MDOT did not request assistance to flood fight those sections in order to keep the highway open.

iii. Vidalia Area Levee Raises. Several locations along the Mississippi River Levee near Vidalia, LA were identified as deficient and in need of raising. Between 4 May and 14 May, these areas were repaired using HESCOs and potato ridges.

a. 357-R, 350-R, 365-R. An ongoing construction contract for enlargement of Item 365-R on the Mississippi River Levee with Kingridge Construction was modified to perform emergency measures on Items 365-R, 357-R, and 350-R. Chancellor and Sons was a major subcontractor involved in this work. Each deficient area required potato ridge, HESCO, or both in order to raise the levee to the required grade and provide a minimum freeboard based on the predicted water level. Potato ridges are small temporary earthen berms and HESCOs are large metal baskets lined with cloth that are filled with sand. Work on these items began on 4 May and continued 24-hours per day until completed on 14 May.

- Item 357-R. 13,800 LF of potato ridge and 5,100 LF of HESCO Bastions
- Item 365-R. 675 LF of potato ridge
- Item 350-R. 700 LF of potato ridge

b. 420-R, 379-R, and Delta, LA. A construction contract for enlargement of Item 420-R with CKY, Inc. was modified to perform emergency measures on items 420-R, 379-R, and adjacent to the old Highway 80 at Delta, LA. Construction related to Item 420-R was ongoing for a portion of the Flood. The contractor was constructing a haul road on the landside toe of the levee using landside borrow material from the old front line levee. Seepage issues increased within the construction limits, and the contractor was directed to suspend work as a precaution to assure construction activity did not adversely affect seepage concerns. Work was suspended for approximately 3 weeks.

- Item 420-R. 310 LF of potato ridge
- Item 379-R. 400 LF of potato ridge
- Delta, LA. 150 LF of potato ridge

iv. Rosedale Sand Boil. On 10 May a significant sand boil was identified in the Rosedale sector near Station 151+00. The Board of Mississippi Levee Commissioners along with convict labor constructed a sand bag ring around the boil. Additional containment was required, and on 11 May Hired Labor and contractors began constructing a dike around the boil. The dike was completed on 12 May.

v. Grand Lake Seepage Berm. On 10 May MVK's Southeast Arkansas Project Office SEAPO was notified by the levee board that moderate seepage and small boils were developing off the toe of the landside berm located in the vicinity of Station 3542 near Grand Lake in Arkansas. This area is adjacent to the mainline levee, which was rapidly loaded when the abandoned front line levee crevasse occurred. The mainline levee on the river side has been historically dry and protected by the abandoned front line levee, therefore never subjected to river loading. Full loading conditions on the mainline levee were experienced 12 hours after the crevasse of the old abandoned levee. The seepage area was sandbagged by the levee board with assistance from the local fire department, but the SEAPO Area Commander decided that the seepage area required an earthen ring levee in order to be stabilized. Construction of a 900 foot long by 3-foot tall levee with plastic lining was completed by the levee board on 11 May.

vi. Silver Street Erosion Protection, Natchez, MS. Significant erosion of the river bank began occurring near Silver Street in Natchez, MS on the week of 8 – 14 May. By 15 May the erosion had begun to threaten the temporary protection measures at Natchez, and the City of Natchez requested assistance from the MVK. The City of Natchez had previously emplaced HESCO bastions near the site, and had used engineering fabric and sandbags to stabilize the river bank.

On 16 May MVK entered into an agreement with the City of Natchez to construct emergency repairs at the site, consisting of emplacement of R200 stone on top of the existing fabric and sand bags along a 350 foot section of eroded river bank. Work was completed by Hired Labor between 16 and 19 May. The City of Natchez removed the top row and one of the bottom rows of HESCO between 18 and 19 May in order to reduce bank loading.

vii. Albemarle Levee Slide. On the evening of 16 May three significant sand boils were discovered in the Mayersville sector near Station 8170+00 on the Mississippi River Levee, which is approximately 8 miles north of Eagle Lake. Additional small boils were identified in that same area on 17 May. The boils were repaired by ringing them with stone and sand, creating a filtered exit. This work was completed on 17 May.

On the afternoon of 16 May a slide was also discovered immediately downstream of the sand boils. The levee slide was 200 feet long with an approximately 3- to 4-foot vertical face. On 18 May another slide occurred upstream of the boil. This slide was approximately the same size as the earlier slide. In order to repair this slide a stone dike was emplaced around the slide area and was backfilled with sand. Hired Labor began work on 19 May by emplacing the stone dike. On 21 May movement of the slide necessitated increasing the quantities of stone and sand required. The northern (upstream) dike and backfill was completed on 22 May, and the southern (downstream) dike and backfill was completed on 24 May.

viii. St. Joseph Sand Boil. On 28 May a very large sand boil was discovered in the St. Joseph sector near Station 6185+75 on the Mississippi River Levee, which is approximately 5 miles south of St. Joseph, LA. This sand boil had a throat diameter of 13 feet and a depth of approximately 18 feet, and was 700 feet from the levee toe. The boil had moved an estimated 100 CY of material.

The Fifth Louisiana Levee District repaired this sand boil by emplacing sandbag dams at both ends of the ditch in which the sand boil formed. These repairs were completed on 30 May.

ix. Wilson Point Levee Overtopping and Crevasse. On 12 May an anticipated overtopping occurred on the abandoned front line levee near Wilson Point north of Lake Providence in Louisiana. The overtopping was expected to impact approximately 10,000 acres of farmland. Because the abandoned levee was lower than the Mississippi River Levee there was no anticipated impact to the levee system except for a rapid loading of the main line levee.

At approximately 2215 on 13 May the MVK was notified that the Greenville gage was slightly falling. Patrols were sent to the Greenville gage area and to the opposite side of the river. The patrols verified the drop based on water marks but could not find a cause of the drop. The immediate concern was that a levee had crevassed.

Levee patrols were conducted along the Mississippi River Levee to identify the cause of the drop, and after verifying that the main line levee was intact suspicion fell on the overtopping levee near Wilson Point. On the morning of 14 May levee patrols verified that the water level on the land side of the abandoned levee was equal to the level on the river side, indicating that a crevasse had occurred in the levee and quickly inundated the land between the abandoned levee and the main line levee. The Greenville gage began falling at 1500 on 13 May and resumed climbing at 0300 on 14 May after a drop of 0.4 feet. The initial actions of the EOC and Greenwood Area Office were to verify the gage drop and to verify the integrity of the main line levees. The gage falling was indicative of a levee failure, and even though the abandoned levee was known to be overtopping it was initially overlooked as the cause of the gage drop.

x. Construction of Weirs in Southeast Arkansas. During this event SEAPO constructed several weirs to control sand boils. These weirs were constructed of sand bags and were lined with polyethylene sheets anchored with sand bags. The first weir was constructed at Station 2150+00 on the Mississippi River Levee northeast of Lake Chicot in a 5,000 foot diversion ditch. Two weirs were constructed on either end of a series of sand boils on 12 May. On 14 May the weirs were raised to increase the water level in the ditch. On 15 May the water level in the ditch was further raised by closing off discharge laterals in the ditch. Clear water flowed over the weirs for most of the duration of the event. SEAPO also constructed weirs at Station 1550+00, north of the Lake Chicot Pumping Plant and at Station 3550+00, north of Grand Lake.

Repairs were made at the weir at Station 1550+00 when soil was washed away from under the plastic, by replacing the eroded soil with sand bags and replacing the plastic sheet. Clear water then flowed over these weirs for most of the duration of the event.

4. New Orleans District

a. Flood Fight Summary. COL Edward R Fleming, the MVN District Commander signed a Declaration of Emergency initiating Phase I of the Emergency Response plan of the MVN, due to a significant flood threat on the Mississippi and Atchafalaya Rivers on 14 March when the water rose to over 11 feet on the Carrollton Gage in New Orleans. On March 15, the MVN EOC elevated the activation to Level II. Phase II of flood fight and level III EOC activation began May 6, 2011 when the water rose to over 15 feet on the Carrollton Gage and remained so until June 26. The MVN EOC returned to normal operations on August 5.

Mississippi and Atchafalaya River peak stages during the 2011 Flood set new records at Knox Landing, Red River Landing, and St. Francisville, and ranked among the top five in most areas throughout the System. This historic Flood required the operation of the Bonnet Carré spillway for only the 10th time since its construction and the operation of the Morganza Floodway for only the second time since its construction. The Old River Control Complex diverted the highest peak flow in its history using only the Hydropower, Low Sill, and Auxiliary Structures; the Overbank Structure was not operated.

Flood Fight mission required over 600 personnel assembled from every department within MVN. During the 2011 Flood, MVN issued or used 1,229,650 sand bags (9,850 large/1,219,800 small), 29 pumps, 524 rolls of polyethylene sheeting, and 44,990 linear feet of HESCO bastions.

The Mississippi River levees experienced an extended period of high water stages. Many seepage and sand boil sites appeared and were flood fought. Damage Assessments were performed for 667 points in all 13 Flood Fight sectors.

The 2011 Flood was an historical event throughout the MR&T Project. Overall, the flood fight was executed successfully in the MVN AOR. Historic flows were safely passed to the Gulf of Mexico in large part due to the exhaustive inspection and response efforts of the Corps as well as the local levee districts.

b. Funding Details

3112 MR&T Appropriation Direct	$7,040,903
3125 FCCE Transferred to MR&T Project	$13,249,130
3125 FCCE Emergency Operations	$3,843,418
Total Flood Fight	**$24,133,451**

c. Chronology of Flood Fight Activities. Table IV-4 on pages IV-27 and IV-28 shows the chronology of flood fight activities in the New Orleans District. All times are CDT.

Table IV-4. Chronology of Flood Fight Activities – New Orleans District

Date	River Events	MVN Events	Other Events
8-Mar	Water level rose at the Carrollton Gage to 8.54 ft	The fore bay of Bonnet Carré Spillway was flooded.	
14-Mar	Water level rose at the Carrollton Gage to 11.0 ft	Declaration of Emergency signed by COL Edward R. Fleming. .	
15-Mar		EOC activated at Level I, emergency watch operation duty hours 0700 - 1730. Lower portions of Mississippi R. activated to phase I flood fight	
17-May	Water level rose at the Carrollton Gage to 11.9 ft	Water was over topping the concrete weir at Bonnet Carré Spillway. Big Mamou sand boil inspected.	
24-Mar	Water level at the Morgan City gage reached 5.0 ft.	The lower Atchafalaya Basin sectors were activated for Phase 1.	
30-Apr	Water level rose at the Carrollton Gage to 12.45 ft	Seepage at Duncan Point; MVN places 122,000 sandbags to form a berm.	
30-Mar	Water level at the Red River Landing gage reached 51.0 ft.	The upper sectors w/in Mississippi River activated for Phase 1.	
4-May	Water level at the Knox Landing gage reached 55.0 ft.	ORCC Hired Labor began sandbagging the Morganza lower guide levee and intersection of lower guide levee with main line levee.	M/V Fred Lee was provided to MVN as a picket boat to monitor inflow channels.
5-May	Water level at the Red River Landing gage reached 54.21 ft.	Phase II flood fight for sectors w/in the entire Mississippi River activated. MVD Commander approved operation of Bonnet Carré Spillway.	
5-May	Monitoring of the scour at the Low Sill Structure was initiated	The Low Sill Structure was fully staffed to monitor and supervise the boom surveys being performed to detect scour upstream of the structure	
6-May	Water level rose at the Carrollton Gage to over 15.0 ft	Phase II flood fight was activated for sectors within the upper Mississippi River. An announcement by MRC was made that the Morganza Control Structure may be opened and the Morganza Floodway may be operated.	Presidential disaster declaration: 26 parishes in Louisiana are declared for public assistance
7-May	Water level rose at the Carrollton Gage to over 15.39 ft	Seepage was noticed by the Chalmette Ferry on Paris Road. Local levee district placed a temp HESCO basket berm on protected side.	
8-May	Water level at the Morgan City gage reached 6.0 ft. Water level of Red River Landing gage reached 55.0 ft.	Phase II flood fight was activated for lower sectors of the Atchafalaya. Approximately 190 sand boils located in the Angola area; 87 were bagged. The others were observed.	
9-May	Water Level rose at the Red River Landing gage to 58.05. Water level rose at the Carrollton Gage to 16.8 ft.	Bonnet Carré Structure was opened. Sand boils were located at Oak Alley. A sand boil was discovered by the Old River Lock.	
10-May		Levee district placed sandbags at intersection of Morganza lower guide and main line levee; placed super bags w/ visqueen in 2 reaches near Waterloo. 1st reach was a 260-ft stretch between Stations 2463+30 and 2461+70; 2nd second reach was 780 ft long between Stations 2475+44 and 2483+24.	
	Water level rose on the Baton Rouge gage to 41.75 ft.	Many sand boils were discovered in a ditch near Port Allen, LA. Weirs were constructed in the ditch to develop a head.	
11-May	Water level rose at the Carrollton Gage to 17.04 ft.	Clear seepage at the toe of the levee was noticed near the Domino Sugar Refinery in Arabi, LA. Seepage also appeared at the Conoco-Philips Plant under the railroad track w/in the plant.	
12-May		Old River Lock closed to navigation	

Table IV-4. Chronology of Flood Fight Activities – New Orleans District

Date	River Events	MVN Events	Other Events
13-May	Water level at the Red River Landing gage reached 61.82 ft.	MRC concurred with operation of Morganza Floodway on 14 May. Pointe Coupee Drainage Structure Closed.	
14-May		MVN activated Phase II for all sectors in the district. Morganza Control Structure opened. Emergency scour repairs completed at ORCC. A 1,600 foot potato ridge levee constructed on the south side of Airline Hwy.	BPNM Floodway operated.
15-May	Water level rose at the Carrollton Gage to 16.96 ft.	2 sand boils appeared at the Algiers area. 330 bays at Bonnet Carre open.	M/V William James arrived to assist the M/V Fred Lee.
16-May	Water level rose at the Carrollton Gage to 16.96 ft.	Seepage discovered in the concrete parking lot at the Port of New Orleans.	
	Water level on the Red River Landing gage reached 62.27 ft.	Sand boils were located in at the James Audubon Bridge near Waterloo, LA. The ditch was bagged to provide head for the sand boil. GIWW Alternate Route closed	
16-May	First detection of scour observed	Standing waves in the tailbay	
17-May	Water level on the Red River Landing gage reached 62.76 ft.	Boil area at Port Allen continued to worsen and road began collapsing.	
18-May		Morganza Control Structure had 17 gates open.	
18-May	First scour Buoy was checked	Scour buoys were only checked once the gate changes began.	Buoys couldn't be checked near open gate.
20-May	Water level at the Carrollton gage read 17.2 ft.	LADOTD closed 1/4 mile of River Rd near Duncan Point due to seepage.	Safety Zone initiated around ORCC.
		Port Allen Lock closed	
21-May	Water level at the Carrollton gage read 16.97 ft.	National Guard added 360 sand bags to the Duncan Point sand bag berm.	
		Berwick Lock closed	
23-May		Port Allen Lock reopened	
24 May		Begin closure of Morganza Floodway structure	
27-May	Water level at the Carrollton gage read 16.8 ft.	2 large sand boils and 4 smaller boils were located on LSU farms. Multiple sand boils were located at Farr Park Equestrian Center and also behind Riverbend Subdivision.	
28-May	Water level at the Red River Landing gage read 61.83 ft.	Erosion due to wave wash was identified near Sugar Lake. Sand bags were placed at water level to decrease erosion.	
31-May		Old River Lock reopened for navigation.	
3-Jun		Berwick Lock reopened	
8-Jun	Last scour buoy was checked	Once discharges were reduced, buoys couldn't be easily checked.	
11 Jun		Begin closure of Bonnet Carre Spillway structure.	
13-Jun		GIWW Alternate Route reopened	M/V William James departed ORCC. Safety Zone around ORCC lifted.
20-Jun		Final needles of Bonnet Carré Spillway Structure closed.	M/V Fred Lee departed ORCC.
21-Jun		Bonnet Carré Spillway was reopened to the public	
23-Jun	Last day on monitoring for scour at the Low Sill Structure.		
25-Jun	Water level at Carrollton gage read 12.4 ft	Seepage through needles of Bonnet Carré Spillway ceased.	
7-Jul		Final gates closed at Morganza Floodway Structure.	
5-Aug	Water level at Carrollton gage read 5.6 ft, Morgan City read 2.9	Flood fight operations ceased in the MVN.	

Figure IV-4. Key Flood Fight Locations in the New Orleans District

d. Key Flood Fight Locations

i. Baton Rouge Front. The unstable flood side slope at *Baton Rouge Front* (figure IV-4) has been visibly moving riverward since 2002. Flood side stability was monitored 24/7 during recent high water to assess potential loss of levee slope (which includes a major railroad atop of crown). The Canadian National railroad was restricted to the use of the landside track only with a reduced speed limit of 10 mph.

ii. Duncan Point. The Duncan Point seepage area contained through-seepage and a sand boil at the landside toe of the levee which also occurred during both the 2008 and 2009 high water events. The seepage at Duncan Point had been getting progressively worse with each event. The lower 1/3 of the landside slope was saturated during these events and has required intensive flood fight efforts. During the 2011 event, head at the levee toe was greater than 10 feet. Spongy conditions developed along the adjacent highway resulting in its closure. A temporary, berm was constructed using 12,000 sandbags to reduce seepage in the most critical reach of the site. A massive aquifer in exceeding 300 feet in depth exists beneath the levee overlain by a thin blanket of confining material, this blanket has been ruptured and the situation continues to deteriorate with successive high water events. The Factor of Safety at the levee toe with water at flowline is 1.15 (vs. 1.6 required).

iii. Chalmette Seepage. The Chalmette Seepage is located at station 175+00.00 Lake Borgne Basin Levee District. There was extensive seepage at this site to include soft, spongy conditions at the levee toe, requiring flood-fight efforts by the local sponsors (construction of a temporary seepage berm using HESCO baskets). Site had to be continually monitored during the flood fight, while an acceptable level of seepage still continued to flow.

iv. Jackson Barracks Slope Paving. The Jackson Barracks Slope Paving is located at Station 690+00.00 OLD. Concrete slope pavement for storm water discharge pipe is cracked, with the potential to undermine slope pavement and discharge foundation during high water events

v. Old River Seepage. Sand boils are on the protected side of the levee at the base of the electric poles that supply electricity to Old River Lock.

vi. Blackhawk Slide. The Blackhawk Slide is located at station 180+00.00 5TH. The Flood Fight team inspection remarked, *"Historical slide from Jan 2010 that was not repaired but was dressed and seeded by MVK hired labor. It is located on the Mississippi River Levee across from Blackhawk on the right descending bank."*

vii. Audubon Seepage. The Audubon Seepage project is located at station 2310-00.00 Atchafalaya Basin Levee District (ABLD). The Flood Fight team inspection remarked, "*3-4 small sand boils in the L/S ditch along the highway directly under the John James Audubon Bridge."*

viii. Pointe Coupee Seepage. The Pointe Coupee Seepage project is located at station 2085+00.00 ABLD. The Flood Fight team inspection remarked, "*Seepage popping up in fresh tractor tracks just upstream of the old New Roads/St.Francisville Ferry. Not sand boil but a seepage hole; Historic seepage popping up beneath the limestone reservation area for a communication tower just above the New Roads/St.Francisville ferry landing and coming out of the edges of the limestone. The seepage is on the levee slope only."*

ix. Point Pleasant Seepage. The Point Pleasant Seepage project is located at station 4950+00.00 ABLD. The Flood Fight team inspection remarked, "*These are historic sand boils in a drainage ditch at Point Pleasant; LA located approximately 900 feet landside of the centerline of the levee. Of 40 visible boils 37 are flowing, 32 are carrying minor amounts of sand material. 14 have 1-inch cones; 6- have 2-inch cones; 5 have 2- to 4-inch cones; 6 have 4- to 6-inch cones; 8 have 6 to 8-inch cones; and 1 has an 8- to 10-inch cone. Standing water in ditch both sides of road LA-405; Large seepage area which* *includes the area behind a church 1/10 mile wide. Location is H Lewis St. at Hwy 405; Seepage at GSU Gas Pipeline. Water is collecting in L/S ditch along River Road. Water is clear. Sand boil is present at the levee toe. Blanket has been fractured.*

x. Algiers Seepage. The Algiers Seepage project is located at station 260+00.00 Algiers Levee District (ALD). This is a known historical seepage area. The Flood Fight team inspection remarked, "*0260+00 ALD: Located in front of mailbox No. 11803. Water is coming from curb at edge of road and from levee toe. Water is mostly clear, brownish color in some locations along curb.*"

xi. West of Berwick. The flood fighting activities that occurred in the areas West of Berwick, LA consisted of placing sheet pile closures across primary gravity drainage canals to prevent any impacts of backwater effects due to high water in Wax Lake Outlet at Calumet. These closures were placed on Hansen Canal, Yellow Bayou Canal, and Franklin Canal.

xii. Bayou Chene. The closure on Bayou Chene was constructed by sinking a barge in the channel and placing HESCO baskets on the top of the barge. The barge was tied in to the channel banks by sheet pile section, with riprap placed on either side.

xiii. Old River Control Complex. The ORCC was constructed to prevent the Atchafalaya River from capturing the flow of the Mississippi River. This objective is achieved by maintaining the distribution of total latitude flow (defined as the sum of the Atchafalaya and Mississippi Rivers flows at the latitude of Red River Landing, LA) between the Mississippi River and the Atchafalaya River at 70 percent and 30 percent, respectively. The ORCC consists of three large water control structures and is located on the RDB of the Mississippi River between RM 304 and 317. These structures include the Old River Low Sill and Overbank Structures that began operation in 1962 and the Auxiliary Structure completed in 1986. A privately owned and operated Hydroelectric Power Station (S.A. Murray, Jr.) is located immediately upstream of the overbank structure. The Old River Lock is located about 8 miles downstream of the ORCC.

Emergency Operations at the ORCC are triggered by readings at the Knox Landing gage, located between the Low Sill and Auxiliary Structures. When stages at Knox Landing reach 52.0 feet, flood fight surveys begin. On 15 March, flood fight surveys where requested to begin on 22 March when the Knox Landing gage was predicted to exceed 52.0 feet. When Knox Landing exceeded 52.0 feet on 29 March, the frequency of the structure surveys was increased.

When Knox Landing reaches 55.0 feet, MVN requests a boat be sent to monitor the Mississippi River for vessels in distress that could be pulled towards the ORCC and assist these vessels in avoiding the structures if needed. On 25 April, the ORCC contacted MVK about picket boat availability since the MVN Motor Vessel (M/V) Kent was already at the Bonnet Carré Structure. MVK provided the M/V Fred Lee which arrived on 4 May as requested. As the Knox Landing continued to rise past 55.0 feet, additional assistance for the Fred Lee was requested. The turbulent waters and extreme currents called for backup by a larger vessel. On 15 May, M/V William James arrived from MVK. Due to turbulent waters and strong current at the confluence to the ORCC inflow channels and the Mississippi River, field personnel requested through the EOC to have the Coast Guard implement a safety zone in the vicinity of the ORCC starting on 20 May.

The ORCC diverted flows exceeding PDF flow of 620,000 cfs for 9 days due to high flows on the Mississippi River and relatively low flows on the Red River, but the design flow for the Federal structures was not exceeded. Only the Low Sill, Auxiliary, and Hydropower Structures were operated during the event. Operation of the Overbank Structure was considered but its operational constraints limited the conditions under which it could be operated. Operation of the Overbank Structure is limited to a head differential of 13.0 feet or lower, and flows are also limited until tailwater stages rise (due to operation of the

Low Sill Structure) to submerge the resulting hydraulic jump and prevent damage to the gabion weir. Consequently, the Overbank Structure, if closed, can only be opened during a short window after tailwater stages have risen but before the differential head exceeds 13 feet.

At one point during the event, the increased flows through the ORCC and the unusually low flow down the Red River caused the Red River to flow backward (northward). Eventually, storage in the overbank areas of the Red River was filled and water again began to flow downstream.

Wave wash erosion was spotted behind the Low Sill Structure on the North and South banks behind the wing walls. On May 13 when Knox Landing read 64.13 feet, Contracting Division issued a verbal notification for a contractor from the Lafayette Area Office to perform emergency scour repairs at these walls. The work was performed overnight and completed on 14 May. 471 tons of rock were placed on the north bank, and 633 tons of rock were placed on the south bank. The area was monitored for the remainder of the event. The rock repair was deemed adequate and prevented any further erosion. Minor erosion was also seen at the at the rock dyke tie-in on the inflow side, where the 1973 failure occurred. The wave action moved small rocks and no emergency repairs were necessary.

On 13 June, when the Knox Landing gage read 59.30 feet, the M/V William James departed. The ORCC Team requested through the EOC that the Coast Guard lift the navigation safety zone. On 20 June, the M/V Fred Lee departed the ORCC. By 27 June, when the Knox Landing gage read 59.34 feet, high water surveys were partly discontinued.

Surveys on 17 June, when the Knox Landing gage read 56.99 feet, indicated scouring on the south bank of the inflow channel at the Auxiliary Control Structure. No emergency repairs were required. The same survey also showed significant shoaling of the first 3,000 feet of the channel near the Mississippi River. No emergency repairs were required. Upon further analysis, the erosion at the guide levee banks was attributed to this shoaling, as sedimentation reduced the flow capacity through the inflow channel and redirected flow toward its banks. An inspection on 02 August determined that the continued erosion led to isolated bank failures.

e. Morganza Floodway. The Morganza Floodway is located at RM 280 in central Louisiana. The Morganza Floodway begins at the Mississippi River, extends southward to the East Atchafalaya River levee, eventually joining the Atchafalaya River Basin Floodway near Krotz Springs, Louisiana. The purpose of the floodway in conjunction with the Atchafalaya Basin Floodway is to carry flood water from the Mississippi River to the Gulf of Mexico via the lower Atchafalaya River and the Wax Lake Outlet. The floodway feature, at twenty miles long and five miles wide, consists of a stilling basin, an approach and outlet channel, and two guide levees. The control structure contains a concrete weir, two sluice gates, and 125 gated openings. On 9 May 2011, seventeen scour indicators were installed in the tailbay of the Morganza Control Structure by MVN Hired Labor Units. The structure is designed to pass up to 600,000 cfs of water to the Gulf of Mexico, alleviating stress for mainline levees downstream along the Mississippi River. Operation of the floodway is highly affected by the Mississippi River water level readings at Red River Landing gage located 20 miles north of Morganza.

On 11 March 2011, MVN mailed the annual written notices to all interests and landowners within the Bayou Des Glaises Loop, Old River Control Structure Project, West Atchafalaya Floodway, Atchafalaya Basin Floodway, and Morganza Floodway, reminding them of the possibility of the floodway operation. By 30 March 2011, Phase I of flood fight was initiated for the Upper Mississippi Area as the Red River Landing gage reached 51.0 feet.

As the waters began to rise, flood notification letters were prepared for the landowners within the Morganza Floodway advising them of the possibility of the need to evacuate all people and livestock as well as the removal of personal belongs. By 28 April 2011, the letters were delivered.
The decision to operate the floodway is the responsibility of the MVD Commander. On 6 May 2011, an announcement was made that the Morganza Control Structure may be opened and the Morganza Floodway may be operated. The following day a request for rangers from Port Barre Office was made to assist with structure opening. The Morganza Team as well as the Mississippi Sector Command teams communicated regularly with the Coast Guard, levee district, and parishes including: ABLD, St. Mary Levee District, Town of Berwick, Morgan City, Pointe Coupee Parish, Iberville Parish, St. Martin Parish, Iberia Parish, St. Mary Parish, and Terrebonne Parish. Requests to the Kansas City Southern Railroad to slow train traffic to 10 mph once Baton Rouge gage reaches 40 ft. NGVD was also made due to seepage area at north abutment of the Morganza Control Structure. Navigation notices were also issued announcing major impacts to the waterways including the closing of the Old River Lock (ORL_11-40, 6 May 2011); and closure of the Port Allen Lock (PAL_11-43, 10 May 2011).

On 11 May 11, 4500 ft of sand bags and Hesco baskets were placed to shore up the southern guide levee at Morganza Control Structure, which was being overtopped by flood waters. On 17 May 11, the equipment tally at this location was 1720 large sandbags, 7000 small sandbags, and 30 Hesco Baskets.

At 1500 hours on 13 May 2011, the MVD Commander concurred with the MVN Commander's recommendation for operation of the Morganza Floodway and directed the Commander to be prepared for operation within 24 hours. A detailed description and timeline for the operation of the floodway is provided in Section IV.E of this report.

f. Atchafalaya Floodway. During the 2011 Flood, the opening of the Morganza Floodway was a concern for its impacts in the middle and lower Atchafalaya Basin. Beginning on May 24, 2011 the Hydraulics Branch in the New Orleans District began monitoring the water levels in the Atchafalaya Basin Floodway to observe the affects of the additional water introduced to the basin floodway from the operation of the Morganza Floodway. The New Orleans District utilized USGS to install gages in the Atchafalaya Basin Floodway and in the backwater areas east and west of the floodway to better monitor water levels.

The areas of concern were the community of Butte La Rose, the areas west of Berwick, LA, and the areas east of Morgan City, LA. The Hydraulic Branch scheduled teams of hydraulic engineers to go to these areas each day as the forecasted flood crest neared to monitor the actual water levels and to observe any impacts that were occurring as a result of the high water.

i. Butte La Rose, LA. The area of most concern was the community of Butte la Rose, because of its location in the middle of the Atchafalaya Basin. The Atchafalaya River forecast showed that the river would be above flood stage in this area at the time the Morganza Floodway was operated. The concern was that the additional water from the Morganza Floodway, would further raise the water elevations in the community. The hydraulic engineers began monitoring the water elevations on the Atchafalaya River near Butte la Rose and on the back side of the Butte la Rose ridge. It was observed that the high water elevations in the Atchafalaya River were wrapping around the downstream end of the Atchafalaya River Levee and coming back up through the West Atchafalaya Basin Protection Levee Borrow Channel. Water in the borrow channel was flowing north past Butte La Rose into the Henderson Lake area and further into the West Atchafalaya Floodway. During the peak of the flooding, backwater was observed in the West Atchafalaya Floodway as far north as Krotz Springs, LA. The Butte La Rose area experienced only minor flooding. The water elevations on the Atchafalaya River at Butte La Rose crested at 23.1 feet NAVD 88. On the backside in Butte La Rose, peak water elevation reached 19.0 feet NAVD 88, a difference of approximately 3 feet.

ii. Morgan City – Backside. Weeks before the river levels reached flooding conditions, the Mayor of Morgan City, LA asked the New Orleans District to provide him with estimated water elevations of Lake Palourde, based on the NWS latest Atchafalaya River forecast at Morgan City. His concern was that prolonged high water elevations on the Lower Atchafalaya River would flank the lower Avoca Island levee and cause flooding on the backside of the City. Lake Palourde is hydraulically connected to the Atchafalaya River. The MVN's Hydraulics Branch performed an analysis based on historical river data. The purpose of this investigation was to provide best estimated water elevations on Lake Palourde, northeast of Morgan City, based on forecasted water elevations on the Atchafalaya River near Morgan City. The NWS is the official forecasting agency and they produce the forecasted stages for Morgan City. This analysis was performed by applying hydrologic statistical methods to historical data for Lake Palourde in order to determine if a correlation exists with water elevations on the Atchafalaya River near Morgan City. This correlation would provide a tool able to estimate lake stages based on a forecasted stages on the Atchafalaya River.

The results of this analysis illustrated that prolonged elevated stages in the Atchafalaya River could result in stage increases on areas located east of the floodway. When the flows in the Atchafalaya Floodway get high, the stages at the end of the Avoca Island Levee, which extends to about twelve river miles downstream of Morgan City, become elevated. The backwater effects from these elevated stages extend to the Amelia area and eventually up to the Lake Palourde area. With the construction of the Bayou Chene closure by St. Mary Parish Levee District, the backwater effects did not occur.

iii. West of Berwick. Elevated stages in the Atchafalaya River in Morgan City and in Wax lake Outlet can also cause stage increases on the GIWW west of Berwick. High stages on the GIWW in this area have the potential to increase the chance of backwater flooding in many outfall drainage canals for some of the local communities in the area. In order to prevent any possible backwater effect from impacting these areas, the local communities placed closures in three of the largest gravity drainage canals in this area. Hansen Canal, Franklin Canal, and Yellow Bayou were closed to prevent high stages in the GIWW from moving into populated areas.

The Hydraulic Branch of the New Orleans District began monitoring water levels on this three canal closures as well as along the levees in the Bayou Sale Ridge area. The monitoring effort began on 24 may and concluded on 29 May 2011. During this monitoring effort, the stages on the three canal closures were reported as well as the conditions on Bayou Sale Ridge.

g. Bonnet Carré Spillway. The Bonnet Carré Spillway is located 32.8 miles above New Orleans, near the Jefferson Parish and St. John the Baptist Parish borders. It extends from the Mississippi River to Lake Pontchartrain for a length of 5.7 miles. The structure consists of 350 bays, each 20 feet wide, for a total width of 7,000 feet at the weir opening. The structure is designed to divert 250,000 cfs to Lake Pontchartrain under the conditions of the PDF for the MR&T Project. The peak flow through the spillway was 314,000 cfs.

On 8 March, the forebay at the Bonnet Carré Structure was flooded when the Carrollton gage reached 8.54 feet NGVD. By 17 March, water was overtopping the concrete weir of the structure and flowing through the closed needles (The Bonnet Carré Spillways is closed with timber posts, or "needles" rather than gates. These do not provide a watertight seal, so leakage through the structure occurs whenever water levels are above the weir crest). Water typically overtops the low bays at 11.8 feet NGVD and the high bays at 17 feet NGVD. Recreational and borrow activities at the Bonnet Carré Spillway were restricted. Borrow pits remained active until water impacted operations, and the closing of these borrow pits did not impact any levee contracts or completion dates.

Several preparatory measures were taken prior to the opening of the spill way. One bay was tested on 5 April 2011 as part of an emergency preparedness exercise. The M/V Kent arrived at the downstream end of the spillway structure a day prior to the spillway opening to perform picket duty. The USCG implemented a Safety Zone on the Mississippi River in front of the structure. Based on experience during the flood of 1997, 500 CY of sand for sand bags was stockpiled offsite for protection of Airline Highway (US 61). The sand was stockpiled adjacent to the maintenance facility at the Bonnet Carre Floodway.

Safety precautions were taken in expectance of large crowds. Under normal operations, the spillway has contracted law enforcement personnel from St. Charles Parish that cover night and weekend shifts. As a result of the structure opening and high level of public interest, the contract was modified to cover two months of additional personnel at both ends of the structure from 1800 hours to 0600. Park rangers from the Atchafalaya Basin were brought in as well to assist during day light hours. In addition to park rangers and St. Charles Parish law enforcement, the Louisiana Department of Wildlife Fisheries (LDWF), Louisiana Department of Transportation and Development, and Louisiana State Police provided regular patrols on guide levees and public viewing areas.

Stakeholder meetings were held the week prior to opening the structures and the MVN Public Affairs Office put out a press release. The Bonnet Carré team communicated regularly with the Pontchartrain Levee District, St. Charles Parish, Pontchartrain Basin Foundation, US Coast Guard, and the USGS.

The decision to operate the spillway is the responsibility of the MVD Commander. On 9 May 2011, the Bonnet Carré Structure was opened; by 15 May, 330 bays were open. Per the Water Control Manual, the structure was operated to prevent flows on the Mississippi River from exceeding 1,250,000 cfs and to maintain safe levels of freeboard on downstream levees. On 14 May, additional material was placed on the upper guide levee, along Airline Highway (US 61) for additional freeboard. This upper guide levee was under construction when the Bonnet Carre Floodway was operated. A 1,600- foot potato ridge levee was constructed on the south side (front side) of Airline Highway. Approximately eight minor seepage areas were reported along the guide levees. The spur levee at the far end of the spillway was overtopped into the lake, though this resulted in no major consequences. A few gages and four of the original structure needles were lost during operation of the structure. These needles were replaced with new ones

On 22 May 2011, a 26-foot section of the Canadian National railroad bridge within the Bonnet Carré spillway was damaged, leaving the rails suspended without a trestle. Amtrak shuttled passenger between Hammond and New Orleans by bus while the structure was inoperable. Further investigations were conducted by the railroad to ensure no further damage was imminent and the Department of Transportation and Development was contacted to ensure debris from the failure would not threaten the integrity of the piers at Interstate 10. No further damage occurred as a result of this incident. The temporary repairs to the railroad bridge were complete on 28 May and the line was fully reopened to rail traffic. Inspections to the rail bridge continued throughout the event and ongoing work was performed on the line amid traffic.

Throughout the event, park rangers issued citation for unauthorized entry or use of the structure. No vehicles were permitted to ride on the levees or park on the crowns. The railroad was prohibited from stockpiling any materials or parking equipment trucks on the crown of the levee while conducting repairs at the rail bridge. Recreational access to the water was prohibited. Law enforcement and park rangers issued citations and citizens assisted in reporting restricted activities. Approximately 20 citations were issued, 6 for unauthorized entry into the water, the rest for ATV usage or riding/parking on the levees. As a result of events with unauthorized entry into the water, a secondary navigation zone was implemented at the Spillway on 27 May. Both ends of the Spillway, the river end and the Lake Pontchartrain side, were patrolled by the Coast Guard to prevent unauthorized entry.

The Bonnet Carré spillway structure closure began on 11 June, and the structure was completely closed by 20 June. The M/V Kent departed and the Coast Guard lifted the safety zones. The Spillway was reopened to the public on 21 June. By 25 June, when the Carrollton gage read 12.43 feet, water was below the concrete weirs and leakage through the needles stopped.

D. SYSTEM BASED SUMMARY

This section builds on the district flood fight information in the prior section by incorporating knowledge gained from MR&T areas of operation after emergency response activities were complete. Some information is repeated from the previous section to provide a foundation for this increased knowledge. This section of the report is organized by MR&T component and presents the information from a system-based perspective to document overall performance. The assessment of the successes and vulnerabilities of MR&T System components provides insights into potential concepts and actions necessary to better manage future flood risks across district boundaries and throughout the system.

1. Reservoirs. During the 2011 Flood, reservoirs were utilized to attenuate the flood crests and reduce overall impacts. MR&T authorized reservoirs, as well as other reservoirs outside the MR&T project, were utilized. A map showing reservoir travel times to the MR&T system can be found in Appendix A, *Reservoirs*. Table IV-5a lists the reservoirs within MVD and LRD that were utilized, their locations, and the extent to which available storage was utilized. Within LRD, all 79 reservoirs in the Ohio Valley played a role in reducing flood levels. Table IV-5b includes a subset of these reservoirs within LRD that set record pool elevations or were instrumental in the regulation of the Tennessee-Cumberland River system.

Table IV-5a. Reservoirs Utilized

Reservoir	Location	District	Division	Operator		Maximum Flood Control Storage 2011
Saylorville Lake	Johnston, IA	MVR	MVD	Corps	non-MR&T	55%
Lake Red Rock	Knoxville, IA	MVR	MVD	Corps	non-MR&T	82%
Coralville Lake	Iowa City, IA	MVR	MVD	Corps	non-MR&T	18%
Lake Shelbyville	Shelbyville, IL	MVS	MVD	Corps	non-MR&T	24%
Carlyle Lake	Carlyle, IL	MVS	MVD	Corps	non-MR&T	68%
Mark Twain Lake	Monroe City, MO	MVS	MVD	Corps	non-MR&T	25%
Lake Barkley	Grand Rivers, KY	LRN	LRD	Corps	non-MR&T	92%
Kentucky Lake	Grand Rivers, KY	TVA	LRD	TVA	non-MR&T	92%
J Percy Priest	Nashville, TN	LRN	LRD	Corps	non-MR&T	76%
Center Hill	Lancaster, TN	LRN	LRD	Corps	non-MR&T	25%
Dale Hollow	Celina, TN	LRN	LRD	Corps	non-MR&T	75%
Wolf Creek	Jamestown, KY	LRN	LRD	Corps	non-MR&T	7%
Rough River Lake	Falls of Rough, KY	LRN	LRD	Corps	non-MR&T	115%
Patoka Lake	DuBois, IN	LRN	LRD	Corps	non-MR&T	112%
Monroe Lake	Bloomington, IN	LRN	LRD	Corps	non-MR&T	109%
Taylorsville Lake	Taylorsville, KY	LRN	LRD	Corps	non-MR&T	101%
Cave Run Lake	Morehead, KY	LRN	LRD	Corps	non-MR&T	81%
Nolin Lake	Bee Spring, KY	LRN	LRD	Corps	non-MR&T	99%
Brookville Lake	Brookville, IN	LRN	LRD	Corps	non-MR&T	67%
Wappapello Lake	Wappapello, MO	MVS	MVD	Corps	MR&T	100%
Sardis Lake	Sardis, MS	MVK	MVD	Corps	MR&T	55%
Arkabutla Lake	Coldwater, MS	MVK	MVD	Corps	MR&T	100%
Enid Lake	Enid, MS	MVK	MVD	Corps	MR&T	43%
Grenada Lake	Grenada, MS	MVK	MVD	Corps	MR&T	38%

Figure IV-5 illustrates the flood storage available within MVD and LRD in mid-February 2011 relative to the average available at that time during other years.

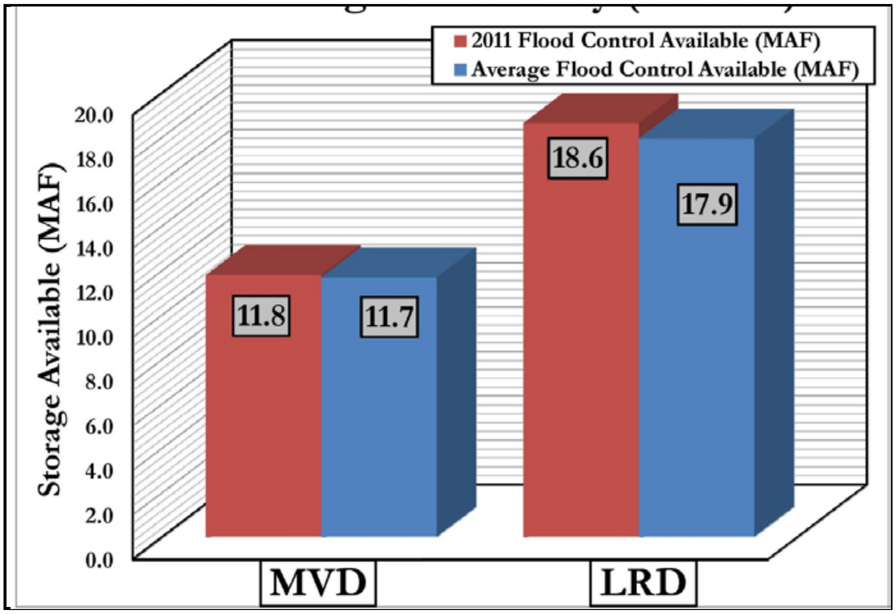


Figure IV-5. Relative Flood Storage Availability – Mid February, 2011 (Million Acre Feet)

a. MR&T Reservoirs. Table 5b lists MR&T reservoirs that were utilized with greater than 50 percent Flood Control Storage during the 2011 event:

Table IV-5b. MR&T Reservoirs Utilized with Greater than 50% Flood Control Storage

Reservoir	Location	District	Division	Maximum Flood Control Storage 2011
Wappapello Lake	Wappapello, MO	MVS	MVD	100%
Sardis Lake	Sardis, MS	MVK	MVD	55%
Arkabutla Lake	Coldwater, MS	MVK	MVD	100%

Additional detailed reservoir information can be found in Appendix A, *Reservoirs*. Due to the record-breaking flood at Wappapello Lake, details related to that event are discussed as follows:

Leading into the 2011 Flood at Wappapello Lake, on April 1 the pool level (355.2 feet) was in the transition range from 354.74 NGVD to 356.74 NGVD, as called for in the Wappapello Lake water control manual. From April 22 through May 3, the St. Francis River Basin received record breaking rainfall. Due to rising pool elevations and forecasts indicating that overtopping of the auxiliary spillway resulting in major damage to downstream roadway and utility infrastructure was probable, a major deviation was requested for Wappapello Lake on April 26, 2011. The deviation plan consisted of constructing a berm at elevation 397.3 feet across the auxiliary spillway. The purpose of the berm was to allow the entire scheduled release discharge of 10,000 cfs to be discharged through the gated outlet structure, and none over the spillway. The berm was located sufficiently upstream of the auxiliary spillway so that it would not impede discharges over the spillway if the berm would be overtopped. The major deviation was approved and was in effect from April 26 through May 2. The pool level crested at 396.7 on April 29 and the deviation was successful.

As a result of a second record rainfall, multiple peak inflows of greater than 100,000 cfs raised Wappapello Lake to a record pool level of 400.04 NGVD on May 3, 0.95 ft above the previous record and 5.30 ft above the auxiliary spillway. The berm which had been constructed across the auxiliary spillway was overtopped (photographs IV-1 and IV-2). Spillway overtopping resulted in significant damages downstream. By June 1, the pool level was down to 377.2 ft and 42 percent of the flood control storage utilized. By July 1, the pool level was successfully approaching rule curve level of 359.74 ft.

Photograph IV-1. Prior to 2011 Overtopping of Spillway

Photograph IV-2. Post 2011 Overtopping of Spillway

The Wappapello Reservoir monthly pool elevation and percent utilization status for 2011 is provided in table IV-6. Figure IV-6 shows a comparison of pool elevations and associated inflow and outflow hydrographs.

Table IV-6. Wappapello Reservoir Pool Elevation & Percent Utilization - 2011

Item	Data	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1
1	Pool Elevation, ft	355.18	354.9	356.96	355.2	396.37	377.2	360.94	360.06	359.87	359.84	359.93	360.82
2	Target Elevation, ft	354.74	354.74	354.74	356.74	359.74	359.74	359.74	359.74	359.74	359.74	359.74	354.74
3	Flood Control Storage % Utilization	0.3	0.1	2.1	0.4	100	41.7	5.9	5.9	5.7	5.6	5.7	7.1
4	All-Time High Pool Elev, ft	389.04	377.14	373.14	395.24	396.37	385.95	389.44	374.24	364.57	366.13	378.67	386.5
5	Period of Record Avg Pool Elev	360.45	358.08	358.1	359.95	363.24	362.82	360.51	359.61	359.15	359	359.7	362.13
6	Average % Flood Control Storage Utilization for Period of Record	6.5	3.4	3.4	5.8	10.9	10.2	6.6	5.3	4.7	4.5	5.4	9.1

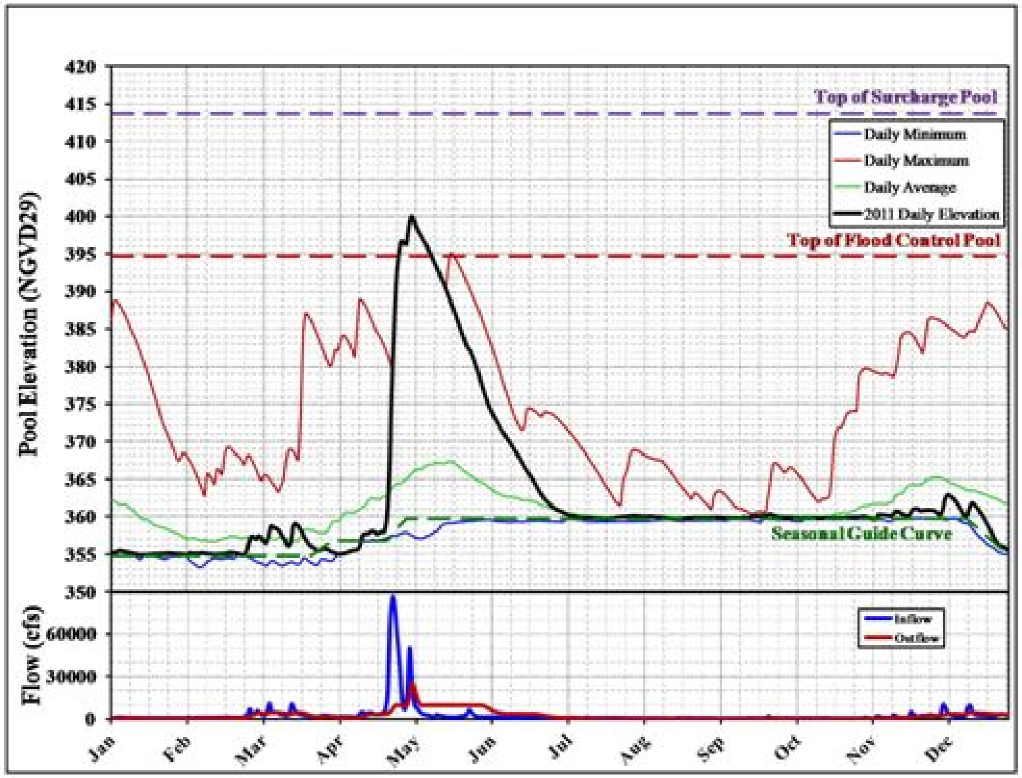


Figure IV-6. Wappapello Lake Elevation, Inflow, and Discharge Comparison Hydrograph

b. Non-MR&T Reservoirs. Several non-MR&T reservoirs located within MVD and LRD were utilized during the 2011 Flood in an attempt to lessen impacts to the MR&T system of their releases. The non-MR&T reservoirs helped to reduce peak Mississippi River stages during the flood. Modeling scenario 3 (section V of this report) included the effect of all reservoirs. Scenario 3 results showed that significant damages were avoided during the flood, due in part to the non-MR&T reservoir effects. At LRD, storage at Lake Barkley and Kentucky Lake was utilized up to the pool of record to reduce stages at Cairo in an attempt to avoid activation of the BPNM Floodway, and protect the lower MR&T system. At Lake Cumberland/Wolf Creek Dam (DSAC I), while only 7 percent of flood control storage was used, the pool reached 45 feet above its interim risk reduction measure lowered pool of 680 feet. This is the highest Lake Cumberland has been allowed to rise since the pool lowering was put in effect as a dam safety interim risk reduction measure. The 7 percent does not truly reflect the large amount of storage that was utilized relative to other issues. These and other reservoirs in LRL contributed significantly to the reduction in the flood crest at Cairo (about 0.53 feet). In addition, several reservoirs with the MVR and MVS Districts operated during the 2011 Flood under a Directive issued by MVD to deviate from their approved Water Control Plans. Those reservoirs, their locations, and the maximum flood storage utilized with and without Directive are provided in table IV-7.

The MVR and MVS Districts were directed to perform deviations from their approved Water Control Plans for Red Rock and Saylorville Reservoirs in the MVR District and Carlyle, Shelbyville and Mark Twain Reservoirs in the MVS District to maintain reduced releases during the Flood in an attempt to minimize flows entering the Mississippi River to effect reductions on the ultimate stages of the Mississippi River. See Appendix A for a copy of the Directive. In addition, releases from Saylorville and Shelbyville Lakes were curtailed due to the need to balance flood control storage with downstream reservoirs.

These Directives were initiated as early as April 25, 2011 through coordination with the Watershed Division. The extraordinary floods which occurred on both the Upper Mississippi and Ohio Rivers were expected to push the stage at Cairo, IL, to exceed the 1937 peak of 59.51 feet by as much as a foot on or about May 1. Record stages were forecasted to occur on the Mississippi River below Cairo as well. The historic flood placed tremendous pressure on the entire FRM system requiring water management measures beyond the normal water control plans.

The MVR and MVS Water Management Offices expressed to the Watershed Division Office that they were not in favor of the Directive because local flood control was “lost” to attempt to provide reduced risk downstream, and because commensurate off-setting positive impacts were not communicated to the Districts. Subsequent analysis during this PFR effort indicates that compared with modeled stages without Directive operations, the crest at Cairo IL with the Directive was reduced by 0.01 feet, a slight positive impact (figure IV-7). Due to the travel time of releases from the reservoirs to Cairo and the timing of the directive, the effect of flow reductions reached Cairo after the crest had already passed for three of the four reservoirs operating under the directive, and on the same day for one reservoir (table IV-8).

Table IV-7. Non-MR&T Reservoirs Utilized

District	Division	Reservoir	Location	Operator	Maximum % Flood Control Storage 2011	Est. Max. % Flood Control Storage 2011 w/out Deviation Directive	Notes
MVR	MVD	Saylorville Lake	Johnston, IA	USACE	55	54	Operated under normal conditions, no change in storage used.
MVR	MVD	Lake Red Rock	Knoxville, IA	USACE	82	79	Difference equivalent to increase of 0.9 feet in pool elev impacting flowage easement agricultural landowners in pool
MVR	MVD	Coralville Lake	Iowa City, IA	USACE	18	18	Operated under normal conditions, no change in storage used.
MVS	MVD	Lake Shelbyville	Shelbyville, IL	USACE	24	18	Difference equates to 1.8 feet of pool elevation.
MVS	MVD	Carlyle Lake	Carlyle, IL	USACE	68	60	Difference equates to 1.2 feet of pool elevation.
MVS	MVD	Mark Twain Lake	Monroe City, MO	USACE	25	25	No difference in peak elevations, but opportunity to operate for fish spawn was lost due to directive operation.
LRN	LRD	Lake Barkley	Grand Rivers, KY	USACE	92	92	Operated under normal conditions, no change in storage used.
TVA	LRD	Kentucky Lake	Grand Rivers, KY	TVA	92	92	Operated under normal conditions, no change in storage used.
LRN	LRD	J Percy Priest	Nashville, TN	USACE	76	44	Deviated 4/26 to 5/5. 44% assumes no flood threat to Nashville, may have been higher if QPF/stage forecasts had indicated a need to reduce flows.
LRN	LRD	Center Hill	Lancaster, TN	USACE	25	0	Deviated 4/24 to 5/7. Operating under IRRM, peak without reductions would have been below bottom of flood pool.
LRN	LRD	Dale Hollow	Celina, TN	USACE	75	50	Deviated 4/25 to 5/6.
LRN	LRD	Wolf Creek	Jamestown, KY	USACE	7	0	Deviated 4/25 to 5/7. Operating under IRRM, peak would also have been below bottom of flood pool.
LRL	LRD	Rough River Lake	Falls of Rough, KY	USACE	115	115	Record Pool; Flow through uncontrolled spillway
LRL	LRD	Patoka Lake	DuBois, IN	USACE	112	112	Record Pool; Flow through uncontrolled spillway
LRL	LRD	Monroe Lake	Bloomington, IN	USACE	109	109	Record Pool; Flow through uncontrolled spillway
LRL	LRD	Taylorsville Lake	Taylorsville, KY	USACE	101	101	Record Pool
LRL	LRD	Cave Run Lake	Morehead, KY	USACE	81	81	Record Pool
LRL	LRD	Nolin Lake	Bee Spring, KY	USACE	99	99	Record Pool
LRL	LRD	Brookville Lake	Brookville, IN	USACE	67	67	Record Pool

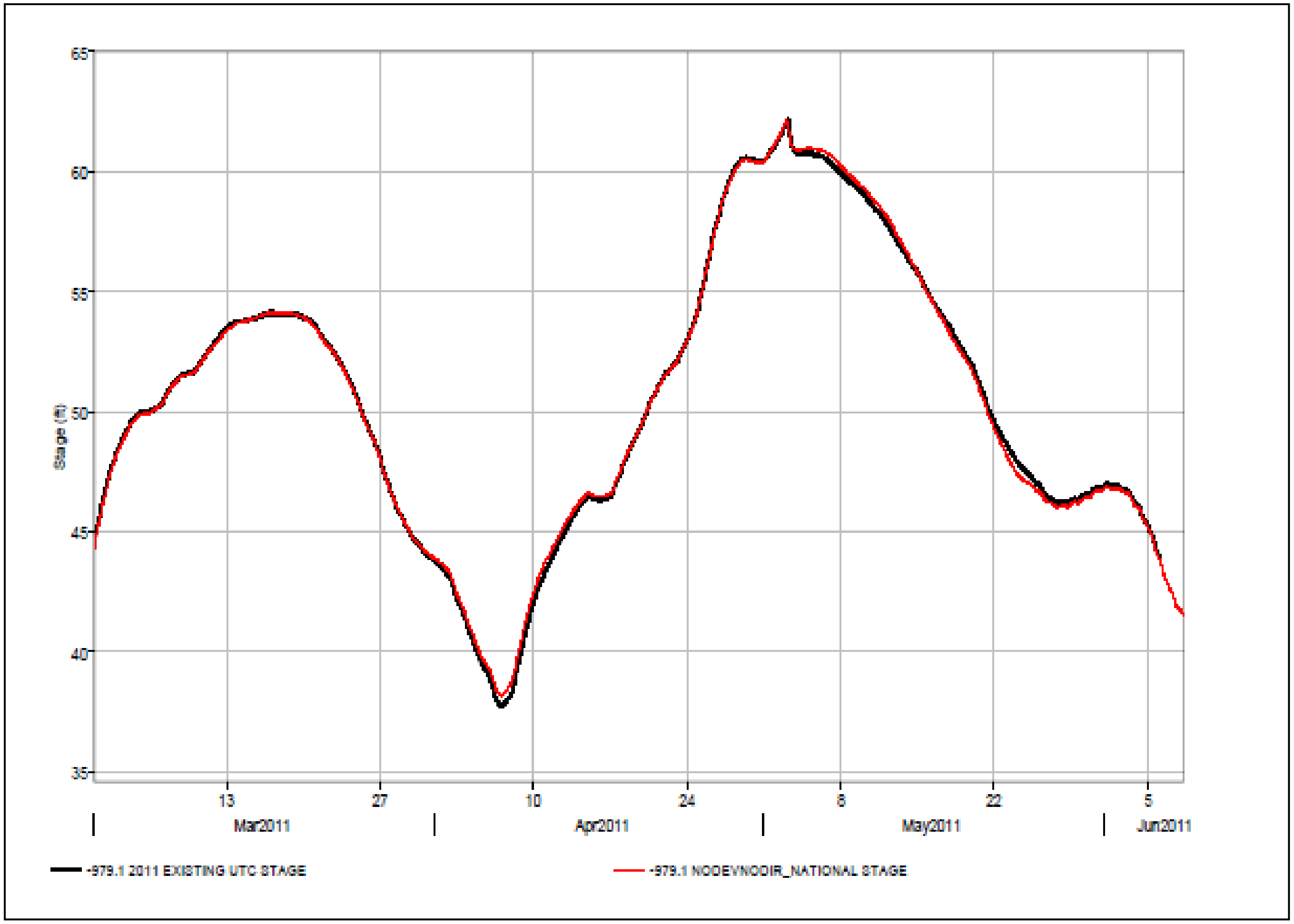


Figure IV-7. Impacts of the Directive on the Stages at Cairo, IL

Table IV-8. Travel Time to Cairo, Deviation-Directed Reservoirs

Reservoir	Date Directive Initiated	Reservoir Flows Est. Travel Time	Arrival Date of Reservoir Flows	Mississippi River Crest Date at Cairo	Reservoir Flows Arrival Relative to Cairo Crest
Mark Twain	4/26/2011	7 days	May 3, 2011	May 2nd @ 2100	After
Shelbyville	4/26/2011	9 days	May 5, 2011	May 2nd @ 2100	After
Carlyle	4/26/2011	6 days	May 2, 2011	May 2nd @ 2100	Same Day
Red Rock	4/27/2011	11days	May 8, 2011	May 2nd @ 2100	After

Negative impacts of the Directive at Lake Red Rock (MVR) included the inundation of about 1,000 occasional flowage easement (not fee title) acres. The 1,000 acres of flowage easement land flooded in Lake Red Rock's flood pool were flooded due to conditions not considered in the water control plan. At Carlyle Lake (MVS), operation under the directive contributed to the lake reaching its second-highest elevation for the period of record, in spite of proactive early-season MVS efforts with local stakeholders to prepare for anticipated heavy spring rains by utilizing deviations for higher than normal releases. Due to the impact of the directive, MVS requested and was granted a deviation to release up to the maximum allowable release of 10,000 cfs until the end of May 2011. This resulted in more available flood control storage at Carlyle, which in turn allowed releases to be increased from Lake Shelbyville (located higher in the watershed).

Stakeholders found it difficult to understand why changes to reservoir operation was needed during the 2011 Flood, and additional time was required to explain why this was being done to attempt to balance flood risks throughout the Mississippi River Basin. Additional details related to how the reservoirs operated under a directive to attempt to minimize flows into the Mississippi River can be found in Appendix A, *Reservoirs*.

2. Levees and Floodwalls. During the 2011 Flood, each District deployed personnel to patrol and monitor the levees and floodwalls that comprise the protection system for their respective District. These personnel are trained by their Districts to identify problematic phenomena that occur during a riverine flood event and report these inspection sites back to their District's EOC. The EOC, in conjunction with District Engineers, develop courses of action to remediate the damaged areas, coordinate the efforts through various local entities, and manage the overall flood fight effort for their District. Typical sites of concern along levee and floodwalls during a high water event are seepage, sand boils, levee sloughing or sliding and freeboard deficiencies. Remedial action for these phenomena can range from merely monitoring the site to an expedited emergency repair.

During the Flood, each system in the MVD was monitored closely and damage was observed and recorded. A summary for each system follows. A more detailed report is found in Appendix B, *Levees and Floodwalls*.

a. SYSTEM #4001 – Mississippi and Ohio River Levees at Cairo and Vicinity

i. Cairo, IL. Three large high-energy sand boils with sand cones from 8 to 15 feet high developed due to major seepage.

ii. Cairo, IL Parcel 5. Major seepage was observed in the form of multiple large, high energy sand boils along the levee toe and in the sump area of the Goose Pond Pumping Station.

iii. Above Cairo, IL Parcel 2A – Relief Wells. Hundreds of small to medium sand boils were observed during the 2011 event. Most of these boils had throat diameters of greater than 4 inches and cone diameters of 3 to 6 feet or greater. Boils were ringed with sandbags.

iv. Above Cairo, IL Parcel 2 – Slurry Trench. Major seepage was observed in the form of hundreds of small to medium sand boils. Most of these boils had throat diameters of greater than 4 inches and cones diameters of 3 to 6 feet or greater.

b. SYSTEM #4002 – Commerce, MO to St. Francis River

Sand Boils at Gammon Water Berm. Heavy seepage and small to large boils occurred and were rung at the landside toe of the Gammon Water Berms. In addition one large boil was discovered.

c. SYSTEM #4003 – Mississippi and Ohio River Levees at Cairo and Vicinity

Island 8 (Mile 1/0+00 to Mile 15/0+00). Heavy seepage and hundreds of large, high energy sand boils within 100 feet of the levee toe was flood fought in this area.

d. SYSTEM #4006 – Mississippi and White Rivers Below Helena. During the 2011 event, six areas of uncontrolled seepage were observed in this system, including sheet seepage, pin boils and small to medium boils moving moderate amounts of material.

e. SYSTEM #4016 - New Madrid Floodway Levee

i. Segment #75 and Segment #76 – BPNM Floodway – Make Safe and Stable. Following the operation of the Floodway, the crevassed sections of the levees were no longer functional. The MVD Commander issued a memorandum directing the MVM to implement *make safe and stable* operations based on a target elevation (stage) of 51 feet on the Cairo gage to provide a stable base for flood fight operations and subsequent reset operations by 30 November 2011. Restoration of the crevassed sections for *make safe and stable* was later expanded to include reconstruction of the levee at the upper inflow crevasse to provide FRM to a Cairo gage reading of 55 feet (photographs IV-3 through IV-6).

ii. The Birds Point New Madrid Floodway. The restore project consisted of rebuilding the System #4016 levees to full height. At the defined *make safe and stable* elevations, the level of protection for the floodway is minimal compared to the pre-operation level of protection. Full reconstruction of the floodway levees requires other elements of the MR&T system, located adjacent to and upstream of the floodway, be remediated to ensure that they can provide full PDF protection.

Photograph IV-3. Upper Inflow Crevasses Prior to Repairs

Photograph IV-4. Levee Crown Damaged Due to Overtopping

Photograph IV-5. Northern End of the Lower Inflow/Outflow Crevasse Prior to Repairs

Photograph IV-6. Scour Hole at Center Crevasse Extending into Agricultural Field.

f. SYSTEM #4021 – Little River Drainage District of Missouri. During the 2011 event, numerous medium sand boils formed within the collector ditches for the Nash Relief Wells while the relief wells were actively flowing. Based on a survey, it appears that the ditches have been over excavated by up to several feet, allowing the sand boils to form. Multiple areas of shallow slope movement and one levee slide that was categorized as possibly impacting levee performance were present on the landside slope prior to the event.

g. SYSTEM #5901 – West Bank Mississippi River Levee

i. Segment #24 - Lake Bruin (LA 5715+00, 5776+00 - 5800+00). Seven boils with cone diameters varying from 2 to 5 feet were located just off of the bank of Lake Bruin at Melancon Camp. These boils produced a total of approximately 10 yards of silty sand and contributed to the removal of material from behind a concrete seawall. These boils are approximately 250 feet from the levee toe.

ii. Segment #62 - Leland Chute (AR 2150+00). Moderate seepage (photograph IV-7) exiting at the toe of the levee and beyond as well as numerous small to medium sized boils located in a ditch (photograph IV-8) approximately 100 feet beyond the toe of the levee were identified in an approximately 1-mile long reach.

Photograph IV-7. Aerial View Showing Extent of Seepage

Photograph IV-8. Bagged Sand Boil in Ditch

iii. Segment #62 – Lake Chicot (Fish Bayou-AR 2575+00). The site has historically been an area with large boils. Two large, high energy sand boils were exiting the lake bank one foot above the water surface at the south end of Lake Chicot. These boils were located within 15 feet of each other.

iv. Segment #24 - Henderson (LA 2062+00 - 2132+00). This has historically been an active seepage and sand boil area. The site is located in and around an old borrow area that was used to raise levee Item 464-R. There were numerous boils ranging in size from small to medium located in a ditch that runs parallel to the berm toe. The ditch is located approximately 20 feet from the toe of the berm.

v. Segment #24 – Ice Box Hole (LA 1910+00 - 1925+00). Historically, this has been an active area. Multiple boils ranging in size from pin boils to large boils are located in the area. Boils are located 75 to 200 feet from the toe of the existing 150- to 200-foot seepage berm.

vi. Segment #62 – Willow Lake (AR 3750+00). The site has historically been an area with numerous small to medium sized boils; there were numerous medium sized boils and one large boil identified in 2011.

vii. Segment #24 – Lake St. John (LA 6940+00). The site has historically been an area with numerous small to medium sized boils. There were six medium sized, moderate energy boils sand bagged during this event. Several of these were boils that reappeared in existing sandbag rings from the 2008 High Water event.

viii. Segment #24 – Lake St. Joseph (Davis Landing - LA 5220+00-5275+00). The site has historically been an area with numerous small to medium sized boils with heavy seepage. There were several medium sized boils that were bagged.

ix. Segment #62 – Grand Lake (AR 3550+00). This area is located along a stretch of levee that had never been loaded by high water until 2011. The loading of this stretch of levee occurred rapidly as a result of the breaching of an abandoned frontline levee. Two medium sized, moderate energy sand boils were located approximately 50 feet beyond the 400-foot seepage berm toe.

x. Segment #24 –St. Joe (LA 6185+75). A large high energy boil, approximately 4 miles south of St. Joe, LA was located approximately 950 feet landside from toe of levee at Station 6185+75 downstream of a drainage ditch culvert. The boil produced over 100 yards of material.

xi. Segment #24 –Wilson Point (LA 590+00-650+00). This area is located along a stretch of levee that had never been loaded by high water until 2011. The loading of this stretch of levee occurred rapidly as a result of the breaching of an abandoned frontline levee. There are hundreds of pin boils with some larger boils that were bagged in order to raise the head over the boils. There are boils beginning at the toe of the berm, which is approximately 300 feet wide and extends out approximately 1,000 feet.

xii. Segment #62 – AR Station 2250+00. Multiple boils were located in the north end of Lake Chicot and in low lying sloughs that drain into the lake. The boils closest to the levee (greater than 500 feet from the toe) were found several days after the river crested and had moved what appeared to be more than 100 yards of silt and fine sand.

xiii. Segment #24 –Kemp Bend (LA 6442+00). Historically, this has been an active boil site that was addressed with the installation of relief wells. Multiple boils were noted at the upstream end of the line of relief wells in 2008 and with the 2011 Flood. Many of the 2008 boils could not be accessed due to water, but active boils were noted in vicinity. These boils are located approximately

1,500 feet from the levee. Throat sizes range from 2 to 6 inches. These boils have each moved approximately ½ yard of material.

iv. Segment #62 – Lake Chicot Pumping Plant (AR Station 1570+00). Historically, this ditch has required flood fighting by placement of water berms to control sand boils in the bottom of the ditch. Numerous sand boils are located in the collector ditch that empties into the diversion canal northwest of Lake Chicot Pumping plant. There was also seepage exiting the toe of the berm at the northern end of the ditch. The ditch is located approximately 150 feet from the toe of berm. The ditch is 20 feet wide and 7 feet deep. The berm is 90 feet wide at the northern end of the ditch and is 300 feet wide at the southern end.

h. SYSTEM #5921 - East Bank Mississippi River Levee (EBMRL)

i. Segment #34 - Buck Chute – [Station 110+00 Brunswick Extension Levee (BEL)]. In February, 2011, when conditions in the project area were dry, two large sand boils were pumped and inspected revealing voids at boil sources as wide as 20 feet and as deep as 10 feet. The voids revealed no obvious "pipes" that continued downward or laterally from the void bottom. The sides and bottom of the voids appeared to be top stratum, fine grained material. As Mississippi River levels continued to rise and approach flood stages in March 2011, the boil area voids were backfilled with sand material, covered with a nonwoven filter fabric, and either sandbagged or earthen dams were constructed around them. These flood fighting measures were sufficient for the 2009 and 2010 flood seasons; however, in May 2011, with predictions of higher stages on the Mississippi River (eventually cresting at 57.1 feet at the Vicksburg gage on May 19), an emergency berm was constructed over the area which encompassed the worst known boil areas. The berm was a clay dike around the perimeter of the boils area, 3 feet of clean sand material within the dike, and capped with approximately 2 feet of clay fill.

At the toe of the berm, a 10-foot wide, 2-foot thick layer of stone was placed in lieu of the clay fill cap to alleviate pressures in the sand material layer. The toe of the berm was constructed to an approximate elevation 85.0 feet. Because of the high exit gradients for the predicted stages, the known boil areas, and the consequences of failure at this location, it was decided to flood the entire project site by raising water levels in Eagle Lake to approximate elevation 90.0 feet through the use of Muddy Bayou Control Structure. Severe damages were prevented at this site through the use of the aforementioned flood fighting measures; however, the extensive flood fighting measures that were used to get through the 2011 Flood are not a sustainable option for annual flood fighting.

ii. Segment #34 - Albemarle - East Bank Mississippi River Levee (EBMRL Station 8170+00). The initial site assessment identified five medium sized, high energy sand boils at the toe of the levee in an area with no berm. Also found was a significant landside slide immediately downstream of the boils. An additional slide developed over the second night immediately upstream of the sand boils. Both slides were accompanied with and were possibly the result of heavy seepage exiting the slide face and on the slope below. The slides were present in the lower 1/3 of the levee embankment and were relatively shallow in depth. A small slide near the levee toe formed immediately above the sand boils on the third day that connected the two larger slides.

iii. Segment #34 - Francis (EBMRL Station 151+00). A large, high energy sand boil was identified moving significant quantities of silt and fine sand material at the toe of a 200 foot seepage berm. Flow from the boil was estimated at approximately 300 gals/min. This boil appeared to have the potential to result in backward erosion and piping that could eventually lead to loss of berm and levee foundation material. Two additional sand boils were identified approximately 100 – 150 feet from the berm toe. These boils were classified as moderate energy levels and moved approximately 5to 7 CY of material. Heavy seepage and numerous pin boils were noted and monitored along the slope and toe of the berm upstream and downstream of these boils for a reach of approximately 2,000 feet.

iv. Segment #34 - Winterville (EBMRL Station 3714+00). A large, high energy sand boil approximately 30 feet from the toe of a 200 foot berm was identified. The boil was estimated to be flowing approximately 300-350 gals/min and was moving significant quantities of silt and fine sand material (approximately 100 cubic yards). This boil appeared to have the potential to result in backward erosion and piping that could eventually lead to loss of berm and levee foundation material. Four additional medium sized boils were identified within 250 feet of the berm toe. The extent of the boils is from Station 3711+00 to Station 3718+00.

v. Segment #26 - Yazoo MP 89/0+00 to MPO 92/0+00 (Rena Lara). During the 2011Flood, heavy seepage with one large high energy boil, about 40 medium boils, 12 small boils, and hundreds of pin boils were observed in this area.

vi. Segment #34 - Tara – (Station 208+00 BEL-327+00 BEL). Moderate to heavy under seepage and numerous active, medium sized sand boils and pin boils were observed within 50 feet of the levee toe between BEL Stations 208+00 and 327+00 near and around Tara Hunting Camp. Two to three large, high energy sand boils with 12- to 16-inch throats were identified between Stations 210 and 220 that flowed 100+ gallons per minute and transported 5+ CY of fine sand/silt before and during remedial action. These boils were located between 10 and 20 feet from the toe of the levee (photographs IV-9 and IV-10).

Photograph IV-9. Sand Cone on Flowing Boil

Photograph IV-10. Sandbagged Boils Flowing

i. Segment #34 - Avon (EBMRL Station 4917+00). Moderate thru seepage exiting several feet up the levee slope and numerous small to medium sized boils at and beyond the toe of the levee were identified with heavy seepage. Each boil moved silt and fine sand; however none of the boils moved a significant quantity of material.

i. Segment #34 - Leota (EBMRL Station 5615+00). Multiple sand boils were located in and on either side of a drainage ditch at the toe of the existing approximate 200- to 250-foot berm. Three of the boils were medium in size and high energy. Multiple pin boils and heavy seepage were noted to the north and south end of the area. The boils at the toe of the berm appeared in the area first and as the river level increased, multiple boils became active out in the field further from the toe.

ii. Segment #34 – Lake Jackson (EBMRL Station 6050+00). Multiple boils were found in a drainage ditch and low areas located approximately 35 to 75 feet from the toe of the existing 250-foot seepage berm.

iii. Segment #34 – Greenville (EBMRL Station 4035+00). Multiple moderate to high energy sand boils were identified moving large quantities of fine sand in two separate areas on the east side of the railroad tracks approximately 400 feet from the levee toe. There is no seepage berm in this area. Heavy seepage, numerous pin boils and saturated, soft ground was identified in and around the boil areas. The throats on these boils ranged from 3 to 6 inches in diameter and several yards (5 to 8 cy) of material had been transported over a 1000 square foot area; however, most of these boils were producing clear water. There were approximately three high flowing sand boils at approximately 100 to 200 gallons per minute each, and were transporting a significant quantity of fine sand and clay/silt balls. Over 15 to 20 yards of material had already been transported from the boils and material was still being moved. Throat diameter of the boils ranged from 12 to 18 inches.

iv. Segment #34 – Ben Lomand (EBMRL Station 7150+00). Several medium to large sand boils were identified moving moderate quantities of fine sand and silt in a drainage ditch along the toe of the seepage berm and in an open area east of the ditch. All of the sand boils were within 10 to 20 feet of the seepage berm toe.

j. SYSTEM #4401 – Mississippi River East Bank Above Bonnet Carre

Duncan Point. Duncan Point is an area of historic seepage. A massive aquifer in excess of 300 feet deep exists beneath the levee overlain by a thin blanket of confining material. This blanket has been ruptured and the situation continued to deteriorate with successive high water events. The area was previously a historic sand boil; but in 2010, a stabilization berm was constructed. As a result, the seepage moved from the berm to an area north along the protected side toe of the levee. There was extensive seepage at this site to include a sand boil at levee toe and soft, spongy conditions one-third up the levee slope, requiring extensive flood-fight efforts. A temporary, berm was constructed using 12,000 sandbags to reduce seepage in the most critical reach of the site. Adjacent highway experienced spongy conditions requiring closure.

k. SYSTEM #4405 – St. Bernard Polder

i. Chalmette Seepage. The site was first reported on 07 May when the Carrollton gage read 15.39feet. The local levee District placed a temporary HESCO Basket berm on the protected side, but a small amount of seepage still appeared underneath the baskets. There was no flow but the seepage remained at the bottom of the baskets throughout the event. The point site was closed out on 15 July when no visible signs of seepage remained and the Carrollton gage read 10.63 feet. This site has been permanently repaired as of March 2012. The repair incorporated a sheet pile cutoff and approximately 300 CY of embankment.

ii. Jackson Barracks Slope Paving. The cracked concrete slope pavement near Jackson Barracks was a known issue prior to this Flood. The cracked slope pavement is located under the storm water discharge pipes approximately twenty feet downstream from where Delery Street meets the river. The broken slope pavement has been replaced by the New Orleans Sewage and Water Board.

l. SYSTEM #4415 – Mississippi River Westbank – Above Old River

Old River Lock Sand Boils. The sand boils by the Old River Lock were first inspected on 09 May when the Red River Landing gage read 58.05 feet. Sand boils had never been reported in this area prior to this event. Backwater from the Atchafalaya River flowed into Keller's Lake and covered the boils near the light poles.

m. SYSTEM #4425 – Atchafalaya Basin

Audubon Seepage. Sand boil and seepage locations were discovered near Waterloo, Louisiana on 16 May when the Red River Landing gage read 62.27 feet. The seepage sites were located in a highway ditch directly underneath the John James Audubon Bridge.

Significant flood fight activities were required at Charenton Floodgate, Bayou Sorrel Lock, and the East and West Calumet Floodgates. Hesco baskets were added to all these structures and steel plates were welded to the East and West Calumet Floodgate superstructure.

While not tested in the 2011 event, some of the floodwalls are believed to be deficient. In 2010, an assessment of approximately 37 miles of I-wall in the Atchafalaya Basin was performed. Evaluations performed included global stability (considering water to the top of wall and flowline + freeboard.), pile tip penetration, and stickup. At that time approximately 3.1 miles of I-wall indicated some form of deficiency. Since that time, both the flowline (2011) and criteria (2012) have changed. These changes tend to further reduce factors of safety.

n. SYSTEM #4452 – Westwego-Harvey-Algiers

Algiers Seepage. Two sand boils sites were reported within this sector: one at Oak Alley Plantation and one in *Algiers* (photograph IV-11). The Oak Alley sand boil was first reported on 09 May when the Carrollton gage read 16.51 feet. It is located at the intersection of Bessie K Road and River Road. There was no moving material reported and the water flowed clear for the duration of the event. The boil was downgraded to a seepage site on 16 June when the Carrollton gage read 14.62 feet, and the area began to dry on 28 June when the Carrollton gage read 11.48 feet.

Photograph IV-11. Algiers Seepage

3. Floodways. The four MR&T Floodways reduce risk by diverting excess floodwaters from the main channel at key locations and increase floodplain area, lowering crest stages in their vicinities and downstream. Performance of the floodways was assessed through interviews with regulators, operators, and stakeholders, and through analysis of stage and discharge data collected during the flood. The following provides details on the emergency operation activities involving floodway areas. The general locations of the floodways are shown in Section II, Figure II-2 of this report. A more detailed illustration is provided in Plate A-1 of Appendix A.

a. Bird's Point – New Madrid Floodway. The BPNM Floodway is located on the right descending bank of the Mississippi River in Mississippi and New Madrid Counties, Missouri, just below the confluence of the Ohio and Mississippi Rivers. The Floodway is about 33 miles long and 10 miles wide. Its area comprises about 205 square miles of alluvial valley land and is enclosed by Mississippi River project levees, except for a 1,500 foot authorized but uncompleted closure at the lower end which provides a drainage outlet and allows flood backwaters to enter the Floodway. The Mississippi River project levees enclosing the Floodway are the lower portion of the upper St. Francis Levee (hereinafter called the Frontline Levee) which forms the eastern boundary and the Birds Point-New Madrid (BPNM) Floodway Levee (hereinafter called the Setback Levee) which forms the western boundary. The Frontline Levee consists of three parts: the upper fuseplug section, 11 miles in length; the lower fuseplug section, five miles in length; and the section between the two fuseplugs. The fuseplug sections are about 2 feet lower in grade than the remainder of the Frontline Levee except for 12,500 feet in the upper fuseplug for the Inflow Crevasse and 7,500 feet in the lower fuseplug for Inflow/Outflow No. 2. The Setback Levee extends from its junction with the Frontline Levee at Birds Point, Missouri, directly across the Mississippi River from Cairo, Illinois, southwesterly for a distance of about 36 miles and ties in with the St. Johns Bayou Levee near New Madrid, Missouri.

The BPNM Floodway reduces flood stages and prevents the PDF from exceeding the design elevation on the Mississippi River at and above Cairo, IL, and along the east bank levee opposite the floodway. The PDF at Cairo is 62.5 Feet or 332.97 Feet NGVD. The BPNM Floodway is designed to divert 550,000 cfs from the Mississippi River during the PDF and provides an estimated 7 feet of stage lowering in the vicinity of Cairo, with smaller reductions above Cairo and through the floodway reach. Under the current operating plan developed in 1986, the floodway is operated when sections of the frontline levee naturally overtop or are artificially crevassed. The floodway requires a timely operation to ensure it performs as designed during a flood approaching the PDF magnitude. In addition to natural overtopping, the plan of operation involves the placing and detonation of explosives at critical locations. The operation of the floodway is directed by the president of the MRC after consultation with the Chief of Engineers.

During the 2011 Flood, the BPNM Floodway was operated in accordance with the approved Water Control Plan. A detailed description and timeline for the operation of the floodway is provided in Section IV.E of this report.

Overall, the floodway operation was successful in conveying the 2011 Flood. However, by its nature, the operation of the floodway results in significant damage to the frontline levees.

b. Morganza Floodway. The Morganza Floodway extends from the Mississippi River at about RM 280 Above Head of Passes (AHP) southward to the East Atchafalaya River levee, and thence southward to join the Atchafalaya River Basin Floodway at the latitude of Krotz Springs, LA. The Floodway consists of a control structure in the RDB of the Mississippi River levee just above the town of Morganza, Louisiana; a guide levee along the upper side of the Floodway between the Mississippi and Atchafalaya River Levees with a drainage structure (Pointe Coupee Drainage Structure, at the Bayou Latenache crossing); that part of the East Atchafalaya Basin Protection Levee from the Mississippi River to about 3 miles below Lottie (latitude of Krotz Springs); high level crossings for the Texas and Pacific Railway; the New Orleans, Texas, and Mexico Railroad; Louisiana State Highways 1 and 190 (the Texas Pacific Railway and LA Hwy 1alignments are on the control structure itself); a lower guide levee extending from just above Morganza to Lottie, Louisiana; and miscellaneous drainage improvements.

The purpose of the Floodway is to divert water from the Mississippi River into the Atchafalaya Basin Floodway. The Morganza Control Structure and the Morganza Floodway are required to pass up to 600,000 cfs of Mississippi River floodwater, under PDF conditions, to the Gulf of Mexico via the Atchafalaya Basin Floodway and the lower Atchafalaya River and Wax Lake Outlet. The Morganza Floodway is operated to divert sufficient floodwater from the Mississippi River to avoid unacceptable stress to the levees along the main stem of the Mississippi River below the Morganza Floodway. Normal operation includes preventing flood stages from encroaching on freeboard requirements, limiting flows to design discharge of 1,500,000 cfs between the Morganza Floodway and the Bonnet Carré Spillway and limiting flow below the Bonnet Carré Spillway to the design flow of 1,250,000 cfs.

Normal operational procedures for the Morganza Floodway are intended to minimize its impacts on the natural environment. The Morganza Floodway Water Control Manual page 5-10, paragraph 5-04c states:

> *The floodgates should be opened gradually and well in advance of the time full Floodway use is needed so more of the animals have time to escape the rising waters. The USFWS and the Louisiana Department of Wildlife and Fisheries recommend that structure gates should be opened slowly, so that waters rise in the Floodway at a rate of about one foot per 24 hours.*

On May 14, as flood flows approached the design discharge of 1.5M cfs, the Morganza Control Structure was opened due to water levels on the Mississippi River side of the structure threatening to overtop the gates of the structure at elevation 60.0 feet. This overtopping would have made it difficult if not impossible to open gates with water rushing over the top. The gantry crane operators at the structure were directed to take hold of the structure gates in advance of the official opening authorization, because if water had begun overflowing the structure before the opening was authorized it would have been nearly impossible to grab the gate hooks. Initially, one gate was opened to keep the water level in the Floodway from rising too quickly, but later in the evening a second gate was opened. .

The Floodway was operated in accordance with the Morganza Floodway Water Control Manual (updated Feb 2000). Section IV.E details the description and timeline for the operation of the floodway.

Although the Morganza Floodway performed as designed, several areas experienced minor damage. Scouring occurred along the toe and up the slope of the East Atchafalaya River Levee at Sherburne which also washed away the highway located at the levee toe. Significant scouring also occurred on the tailbay side of the structure beyond the limits of the scour protection, along the stilling basin end sill wall and in the concrete plunge pond. If allowed to continue unimpeded this scouring could have affected the integrity of the structure. Additionally, some of the stone from the scour protection area adjacent to the stilling basin was washed out and displaced. The Morganza Forebay South Guide Levee had scoured damage in low sections where sandbags were placed during the flood due to overtopping of the levee. Other scour areas developed along forebay levee slopes due to wind-driven wave action. These levee damages were generally localized and did not significantly affect flood risks for communities along the Mississippi or Atchafalaya Rivers.

The 2011 Flood revealed several deficiencies in the operation of the Morganza Floodway. Although floodway operation is tied to a defined discharge in the Mississippi River, in 2011 Floodwaters nearly overtopped the structure before the discharge reached the level that dictates Floodway operation. Due to geomorphologic changes that are occurring in the Mississippi River, the discharge threshold for operation of the Morganza Structure is resulting in river water elevations that are very close to the top of the structure. Future geomorphic changes could result in operational discharge triggers that result in water surface elevations that exceed the elevation of the structure.

The scour protection in the tailbay was revealed to be insufficient to prevent significant scour damage during operation. A serious scour threat remains because of the type of gates on the structure along with the lack of a means to dissipate the energy of such a high head differential due to the changes in the stage-discharge relationships being observed in the Mississippi River. The South Guide Levee was also shown to be deficient during this event, requiring sandbagging to prevent overtopping. Furthermore, several structure piezometers, scour indicators, and relief wells also failed to function properly.

Many operational deficiencies were revealed by the flood; one required deviation from the Water Control Manual and/or Operations and Maintenance Manual. Some of the scour damage in the tailbay was due to the gate opening sequence required in the Water Control Manual; changing this sequence required an approved deviation in 2011. The Water Control Manual also does not include a stage/storage curve, discharge formulas, or weir coefficients, giving almost no information for how to calculate structure flow. Similarly, the size and inverts of the sluice gates at the structure are not listed in the Water Control Manual, so the discharge through those gates is also difficult to compute. Finally, the pertinent data in the Manual does not reflect the latest staff gage locations, hydrologic data, support agencies, or scour damages and corresponding repairs, if any, due to the 2011 Flood. Operational deficiencies revealed during the flood can only be understood and corrected through an engineering assessment or study, which is warranted for this key structure.

Similarly, the size and inverts of the sluice gates at the structure are not listed in the Water Control Manual, so the discharge through those gates is also difficult to compute. Finally, the pertinent data in the Manual does not reflect the latest staff gage locations, hydrologic data, support agencies, or scour damages and corresponding repairs, if any, due to the 2011 Flood.

c. Bonnet Carré Spillway. The Bonnet Carré Spillway is located in St. John Parish, Louisiana. The Spillway structure is located on the Mississippi River between RM 127 and RM 129 AHP. The spillway itself extends from the Mississippi River to Lake Pontchartrain, approximately 5.7 miles away. The project is part of the MR&T Project in the Lower Mississippi River Basin and operational responsibility belongs to the MVN.

The purpose of the Bonnet Carré Spillway is to divert floodwater from the Mississippi River to the Gulf of Mexico via Lake Pontchartrain. The spillway is required to pass 250,000 cfs of Mississippi River floodwater to Lake Pontchartrain under PDF conditions. The ORCC, Morganza Floodway, and Bonnet Carré Spillway are operated together as needed to divert sufficient floodwater from the Mississippi River to minimize the flood damages in the lower river reaches and prevent discharge in the Mississippi River from exceeding 1,250,000 cfs at New Orleans. Bonnet Carré is normally operated when the flow in the Mississippi River below Morganza exceeds 1,250,000 cfs on a rising hydrograph or to preserve a desired level of freeboard on deficient levees through the New Orleans Area. The spillway is controlled so that the flow below Bonnet Carré in the Mississippi River does not exceed 1,250,000 cfs.

The Bonnet Carré Spillway consists of the following elements: a control structure in the LDB of the Mississippi River levee just above the town of Norco, LA; an upper guide levee extending 5.7 miles from the Mississippi River, with an elevation of approximately 27.0ft, to Lake Pontchartrain, with a levee elevation of approximately 15.0 ft., and a lower guide levee extending 5.7 miles from the Mississippi River, with a levee elevation of approximately 28.0 ft, to Lake Pontchartrain, with a levee elevation of approximately 15.0 ft, ; high level crossings for the Yazoo and Mississippi Valley Railroad, Louisiana and Arkansas Railroad, and the Illinois Central Railroad; and high level crossings for US Highway No. 61 and Interstate 10. The high level crossing for US Highway No. 61 is a bridge crossing with abutments that extend out into the floodway. The west abutment extends approximately 2,700 feet into the floodway with a minimum elevation of approximately 16 feet. The east abutment extends into the floodway approximately 2,300 feet, with a minimum elevation of approximately 16.5 feet.

Significant decisions associated with the 2011 operation of the Bonnet Carré Spillway are as follows:

May 5 – MVD Commander concurred with MVN Commander's request to operate the Bonnet Carré Spillway and consulted with the MRC, who approved it unanimously. MVD Commander contacted Louisiana and Mississippi officials to inform them of the possibility of operation.

May 9 - The first bays were opened at the Bonnet Carré Spillway structure based on a computed discharge of 1,240,000 cfs at Red River Landing on 8 May and an assumed one-day lag time between Red River Landing and New Orleans.

May 12 - it was determined that floodwaters were encroaching on the freeboard of deficient Mississippi River levees downstream of New Orleans. In order to preserve desired freeboard for levees and structures in the New Orleans area from prolonged exposure to high stresses, MVN considers increasing the flow through the Bonnet Carré Spillway beyond the 250,000 cfs it would be required to divert under the Water Control Manual.

May 14. The discharge through the spillway was increased above the design discharge of 250,000 cfs to preserve a desired level of freeboard on these deficient levees, in accordance with the Water Control Manual. This increase above the 250,000 cfs design discharge was approved by the District Commander and a white paper titled "Commanders Assessment" was written to document the reasons for this increase (Appendix C, *Floodways and Backwaters*).

May 17 - at peak operation, 330 of the 350 total bays were open and 316,000 cubic feet of water per second passed through the Spillway.

June 8 – MVN Commander requested a deviation from the Bonnet Carré Spillway Water Control Manual to allow structure closure to begin only after stages at New Orleans had fallen to 15 feet, rather than closing as quickly as possible without exceeding the flow limitation at New Orleans. The purpose of this deviation was to allow stages along levees below New Orleans to fall more quickly, permitting inspection of levees and reducing risk due to a potential hurricane storm surge in the river. This deviation request was disapproved to prevent further water quality impact to Lake Pontchartrain.

June 11 - the MVN began closing the Bonnet Carré Spillway structure.

June 20 - the final gates were closed at the Spillway structure.

Neither the Bonnet Carré structure nor the spillway was significantly damaged during the 2011 Flood. The spillway experienced significant sedimentation over the course of its operation, theoretically reducing the amount of flow it can safely discharge to Lake Ponchartrain, but this is an expected occurrence and an issue to be investigated rather than damage incurred. This sediment will be removed over time by sand hauling companies.

The Spillway performed as needed, passing more flow than its assumed allocation as part of the MR&T system. More flow could have passed through the structure if all bays had been opened, but it is unknown how much more flow the guide levees could have held without overtopping. The effects of greater discharge on velocities in the Spillway are also unknown. Nevertheless, these are not considered deficiencies as they concern discharges greater than the required capacity. There were however deficiencies with the floodway, downstream of the structure. A potato ridge had to be constructed to prevent Airline

Highway from being flooded during spillway operations. It was constructed between the Bonnet Carre Upper Guide Levee and the west abutment of the Airline Hwy Bridge crossing the spillway. This is a major deficiency within the Spillway. The Bonnet Carré Spillway carried more water than its assumed allocation under PDF conditions in order to protect deficient Mississippi River levee sections downstream. These deficient sections could be considered deficiencies of the MR&T system's present state, rather than of the Spillway itself.

d. West Atchafalaya Floodway. The West Atchafalaya Floodway is located immediately west of the Atchafalaya River, paralleling it from the latitude of Simmesport in the north to approximately Krotz Springs in the south. Averaging 5 to 7 miles wide, it is bordered by the West Atchafalaya Basin Protection Levee on the west and the West Atchafalaya River Levee to the east. Across the northern end of the Floodway between Simmesport and Hamburg is a 7.5-mile long fuseplug levee. The purpose of the West Atchafalaya Floodway is to lower stages in the Atchafalaya River, the Red River backwater area and the Mississippi River through the natural overtopping or artificial crevassing of the 7.5-mile long fuseplug levee, and/or through the natural overtopping of the West Atchafalaya River levee below Simmesport. Operational responsibility belongs to the MVN. The West Atchafalaya Floodway was not utilized during the 2011 Flood because of low stages on the Red River. The Floodway was not damaged during the 2011 Flood and no physical or operational deficiencies in the Floodway were revealed.

e. Old River Control Structure Complex (ORCC). Although the ORCC is not a Floodway, its operation is integral to the MR&T system and the potential operation of the West Atchafalaya Floodway and the Red River Backwater Area, and operations at the ORCC both influence and are influenced by operations at the Morganza Floodway. The project is located on the west bank of the Mississippi River between RM 304 and RM 316 AHP and 50 miles northwest of Baton Rouge, LA. The project provides for the control of flows from the Mississippi River into the Atchafalaya River and Basin. The primary purpose of the project is to prevent the Mississippi River from changing its course to that of the Atchafalaya River, which it achieves through regulation to provide a distribution of flow and sediment from the Mississippi to the Atchafalaya River equivalent to that which occurred naturally in 1950. Specifically, the ORCC is regulated to maintain a distribution of total flow in the Mississippi and Atchafalaya Rivers such that 70 percent of that flow is contained in the Mississippi River and 30 percent in the Atchafalaya River.

The project consists of an Auxiliary Structure, a Low Sill Structure, an Overbank Structure, an integrated levee system, and a navigation lock and highway bridge. A privately owned hydroelectric power station is allowed to divert some of the required flows for power generation.

The ORCC performed as needed during the 2011 Flood, but several unexpected effects occurred. The ORCC is regulated based on the flow in the Mississippi River at Red River Landing and in the Atchafalaya River at Simmesport, both of which are downstream of the ORCC. When the Red River rose out of its banks and began occupying side-channel and overbank storage, excess flows from the ORCC flowed north up the Red River rather than south down the Atchafalaya River, causing the Atchafalaya's share of latitude flow to trend lower than the typical 30 percent. Similarly, when the flood was receding and water was draining out of storage on the Red River, the opposite effect occurred, causing flows at Simmesport to tend to be higher than 30 percent of latitude flow; further decreases in ORCC discharge only served to draw more water out of storage.

Late on the night of 13 May, the Engineering Division and Hydraulics and Hydrologic Branch Chiefs were monitoring freeboard at the Morganza structure and became concerned about possible overtopping there during the night, so the decision was made to perform a gate change at the Auxiliary Structure to increase the flow through the complex for the sole purpose of ensuring that overtopping would not occur at the Morganza Control Structure. The areas of the Morganza Structure called curtain walls were especially vulnerable because there was no overtopping resiliency there. Overtopping in these areas had the potential to propagate into greater distress at the structure with the further potential to compromise the operation. This decision resulted in an increased total ORCC flow. This had the desired effect of preventing overtopping at Morganza but also altered the distribution of flows between the two rivers for several hours until the next gate change at ORCC on 14 May.

Scouring of the bank occurred behind the wing walls on the outflow side of the Low Sill Structure. Construction Division issued an emergency stone placement contract and was able to stabilize the banks. Additionally, issues and concerns were raised regarding sediment build-up in the inflow channels of the Auxiliary and Low Sill Structures. A large scour hole formed just behind top of bank On the LDB of the Auxiliary inflow channel near its mouth.

Old River Lock was closed due to high water stages. Electrical equipment for the operation of the lock was removed in the affected areas until the water stages drop to a safe operation level. Plates were added to the top of the Mississippi River end gates and sandbags were placed on the guide walls to maintain required freeboard.

Two major operational deficiencies at the ORCC were identified during the 2011 Flood. The ORCC is regulated to maintain a flow balance, with flows measured through the use of stage-discharge rating curves. These curves relate a change in stage to a change in discharge, as plotted based on measured stages and discharges. However, once the Morganza Floodway was operated, stages at the nearby ORCC almost ceased to change, though the discharge continued to change, since the Morganza structure was being regulated to prevent further rises. This made the rating curve method unusable and therefore made regulation of discharge highly uncertain until the Morganza structure was again closed.

The other operational deficiency relates to the Overbank Structure. This structure was designed to be operated under a limited differential head (8 feet when fully open, 13 feet when used in staggered-panel configuration). Furthermore, to avoid damage to the gabion field downstream of the structure, flows through this structure are limited to minimum outflow channel stages to prevent a hydraulic jump from forming. The decision not to use the Overbank Structure was predominately based upon a lack of confidence in the downstream weir. The use of the Overbank Structure is essential to provide operational flexibility to the ORCC to adjust for unforeseen emergencies. Ability to fully utilize the Overbank Structure would allow reducing flows through the Low Sill Structure resulting in less stress on the inflow training walls and adjacent embankments, and the inflow and outflow channels near the structure. .

4. Backwaters. The four major backwaters of the MR&T system serve to reduce flood crests on the Mississippi River and some of its tributaries by storing excess water under severe flood conditions. They function through the use of fuseplug levees, which are intentionally constructed to a lower grade than mainline Mississippi River levees, so that when overtopped they store water off of the main channel and thus lower stages nearby and downstream. However, because these backwater areas were constructed in areas of natural overbank and side-channel storage, natural backwater effect can store water and lower crests even when the fuseplug levees of the authorized backwater areas are not overtopped.

a. St. Francis River Backwater Area. The St. Francis River Backwater Area is located near the confluence of the St. Francis and Mississippi Rivers in Lee and St. Francis counties, Arkansas. The area is bounded by the St. Francis Levee system on the east and Crowley's Ridge on the west. The levee includes a 9 mile long fuseplug section near the W. G. Huxtable Pumping Plant, both located near Marianna, AR. The purpose of this backwater area is to store excess floodwaters from the St. Francis and Mississippi Rivers under PDF conditions, lowering peak stages on the Mississippi River. The backwater area is placed into operation by overtopping of the fuseplug levee when stages start to approach PDF elevations. This fuseplug levee has an elevation three feet below the MR&T PDF flowline and one-half foot above the stages experienced in the backwater area during the Flood of 1937. The 12,000 cfs W. G. Huxtable Pumping Plant is designed to remove runoff impounded within the backwater area by the levees flanking the Mississippi and St. Francis rivers by pumping when gravity flow through its gates is insufficient to drain the backwater area. Its four gates, each 28 feet wide by 27 feet tall, are closed when the elevation of the Mississippi River approaches 177 feet above sea level or exceeds the elevation of the St. Francis River. Under such conditions, the pumps are placed into operation until the level of the St. Francis River drops below an elevation of 175 feet above sea level.

Although flooding occurred outside the levees in the vicinity of the mouth of the St. Francis River, the fuseplug levees at the St. Francis River Backwater Area were not overtopped and the backwater area was not operated during the 2011 Flood. Crest stage at the Huxtable Pumping Plant during the 2011 Flood was 202.6 feet NGVD29, whereas the fuseplug levee elevation at the same location is approximately elevation 209 feet NGVD29 for most of its length, with a section at its lower end that is below the 207 foot design grade. Crest elevation on the landside at the Huxtable Pumping Plant during the 2011 Flood was 192.4 feet NGVD29.

b. White River Backwater Area. The White River Backwater Area is located in Desha and Phillips counties, Arkansas, near the confluence of the White and Mississippi Rivers. It consists of a 40-mile-long backwater levee stretching from the frontline levee at Laconia Circle, AR along the east side of the White River until it reconnects with the frontline levee near Old Town, AR, as well as floodgates on Little Island Bayou (draining to the White River) and on Deep Bayou (draining to the Mississippi River), and the 1,500 cfs Graham Burke pumping station. The backwater area is placed into operation by overtopping of two fuseplug levee sections on the White and Mississippi rivers when stages on those rivers start to approach PDF elevations. The two floodgates serve to evacuate impounded runoff within the backwater area, with the pumping station operating when stages on the White River do not permit gravity drainage through the Little Island Bayou structure.

Although there was significant flooding in the White River floodplain, some of which was caused by backwater from the Mississippi, the White River Backwater Area was not operated during the 2011 Flood, as stages did not reach sufficient height to overtop the fuseplug levee sections. Crest stage at the Graham Burk Pumping Plant during the 2011 Flood was 168.5 feet NGVD29, whereas the fuseplug levee elevation at the same location is approximately elevation 177.5 feet NGVD29. Stages on the interior of the backwater area peaked at 149.7 feet NGVD29.

Significant deficiencies revealed for the White River Backwater Area include areas of under-seepage into the backwater area, debris deposition in unprotected areas, and overtopping of a short reach of the Augusta-Clarendon levee. This levee is approximately 39 miles long, extending from RM 192 to 115 along the LDB of the White River and protecting approximately 650,934 acres of agricultural land. The Augusta to Clarendon project flowline is based on the 1938 flood on the White River. High water data from the 2011 Flood indicate that the crest elevation along the overtopped section of levee exceeded the project flowline by about 1 foot. This overtopping caused damage to the levee during the period of 25 April to 30 May 2011. Landside levee crown material was windrowed on the riverside levee crown to create a taller flood barrier structure to prevent further overtopping. A short section of levee was unable to be protected from overtopping. Minimal damage occurred to the levee along the overtopped portion and very few additional acres were inundated on the landside of the levee, because significant flooding was already occurring along the Cache River.

c. Yazoo River Backwater Area. The Yazoo River Backwater Area is located in Warren and Issaquena counties in Mississippi, near the confluence of the Yazoo and Mississippi Rivers. It consists of a backwater levee connecting with the frontline Mississippi River levee near Vicksburg and extending along the west bank of the Yazoo River to Yazoo City, as well as drainage structures on the Little Sunflower River and Steele Bayou. The backwater area is placed into operation by overtopping of the backwater levee, which is lower than the mainline Mississippi River levee.

The Yazoo River Backwater Area was not utilized during the 2011 Flood, as the backwater levee was not overtopped. However, the protected side of the backwater levee was armored and some deficient sections were brought up to authorized grade in anticipation of overtopping, as crest stages reached within inches of the levee crown. The peak stage on the interior of the Backwater Area was 90.0 ft NGVD 29, just over 16 feet below the riverside elevation. Section IV. E, *Key Operational Decisions* provides further details on the Yazoo River Backwater Area efforts during the 2011 Flood.

d. Red River Backwater Area. The Red River Backwater Area is located in Avoyelles and Concordia Parishes in Louisiana, near the confluence of the Red and the Black Rivers. It consists of a 93-mile backwater levee along the east banks of the Red, Black, and Tensas Rivers, the lower 38 miles of which are built three to four feet below the grade of the Mississippi River Levee at Red River Landing and serve as a fuseplug to allow water to enter the backwater area under PDF conditions. There is also a drainage structure through the levee at the mouth of Bayou Cocodrie (draining to the Red River) and a combination drainage structure and 4,000 cfs pumping plant at the mouth of Wild Cow Bayou (draining to the Black River). The purpose of the backwater area is to store excess water from the Mississippi, Red, Ouachita, Boeuf, and Tensas Rivers during extreme floods. Under the original MR&T flood control plan adopted by the 1928 Flood Control Act, this area would also have stored water from the Boeuf and/or Eudora floodways, which were never constructed.

The Red River can store large amounts of water in its overbanks even without overtopping the fuseplug levee. Typically, the Red River will overflow its banks when stage at Barbre Landing, LA (at the confluence of the Atchafalaya River and the Old River Lock Channel) exceeds 40 feet.

The Red River Backwater Area was never operated during the 2011 Flood, as the fuseplug levee was never overtopped. However, a significant amount of floodwater was stored in the overbank areas of the Red River, between the backwater levee and the Marksville, LA area. This storage was evidenced by the relatively unchanged flow of the Atchafalaya River at Simmesport, LA, despite rapidly increasing discharge through the ORCC. The storage effect was also measured in the field as crews from both the Corps and the USGS measured negative (northward) flow in the Red River during the period of greatest discharge through the ORCC. The peak stage on the interior of the Red River Backwater Area in 2011 was 34.1 feet NGVD29, measured on Bayou Cocodrie at Shaw.

No damages were detected at the Red River Backwater Area as a result of the 2011 Flood. No operational or physical deficiencies were detected at the Red River Backwater Area as a result of the 2011 Flood.

5. Interior Drainage Systems. Throughout the basin, there are many areas protected from headwater and backwater flooding which rely on gravity drainage structures as interior drainage outlets. During floods, these structures are closed and the impoundments of seepage and rainwater can cause interior flooding of serious proportions. In some cases, pumping stations which would address the problem are authorized. In other cases, areas are allowed to become inundated, or portable pumps are utilized by the Corps or others.

There was variance in the amount of rainfall within the three lower districts. Rainfall in the MVK was higher than the annual average which impacted the operation of interior drainage structures. Conversely, the MVN was experiencing a drought and therefore experienced limited impact to interior drainage. Any additional rainfall during the flood would have resulted in greater impacts and, as a result, a greater need for emergency measures.

In addition to the following issues, interior drainage was impacted throughout the LMRV by seepage and blockage in locally operated drainage canals. In regards to seepage, the impacts were limited because it could be pumped into adjacent bodies of water or back into the Mississippi River. Nonetheless, seepage was an issue during the height of the event and proper resources had to be allocated for response. During the 2011 Flood, there were instances of blocked drainage due to debris in drainage canals. Clearing and snagging is the responsibility of the local sponsor and must be done prior to the floods.

a. St John's Bayou – New Madrid Floodway. The St. John's Bayou project is located in the Bootheel area of Missouri. It covers two drainage basins adjacent to the Mississippi River: the St. Johns Bayou Basin (450 sq mi) and the New Madrid Floodway (203 sq mi). The St. Johns Bayou Basin is bounded on the east by the BPNM Floodway Setback Levee and on the west by Sikeston Ridge and the Farrenburg Levee. St. Johns Bayou is the drainage outlet of the basin and empties into the Mississippi River through the St. John's Bayou Gravity Structure (SJBGS). The structure crosses State Highway P and is located approximately ½ mile upstream from the Mississippi River. The SJBGS contains six 10 by 10 foot box culverts.

During high water events on the Mississippi River, floodwaters back into the BPNM Floodway thru a 1,500-foot opening at the southern end of the floodway. The SJBGS is closed to prevent Mississippi River backwater flooding. Interior rainfall/runoff is stored in the sump area until gravity flow is permissible.

During the 2011 Flood, the SJBGS was closed. Multiple major rainfall events which contributed to the high Mississippi River stages were also impacting interior drainage. More than two thirds of the BPNM Floodway was inundated due to backwater flooding when it was operated for the second time in its history. The SJBGS prevented flood waters from entering into St. Johns Bayou Basin, but Mississippi River water levels did not permit gravity drainage through the structure for approximately 70 days.

b. St. Francis River Basin. The St. Francis River flows from Lake Wappapello, MO, to the confluence with the Mississippi River, approximately 10 miles north of Helena, AR. The St. Francis River Basin project contains levees and channels which are 100 percent federally maintained. The drainage design capacity was approximately a 10 year frequency during the crop season and the levee design was approximately a 25-year frequency with 3 feet of freeboard. Recent analysis indicates that levees have approximately a 100-year level of protection with 2 feet of freeboard.

Within this basin, there are two pumping stations—Drainage District #17 (DD#17) and W.G. Huxtable Pumping Plant—built, maintained and operated by the Corps. DD #17 is located east of the Big Lake Floodway and is the outlet for a 33 square mile area. The pumping station removes interior runoff from DD#17, which includes the communities of Gosnell and Blytheville, AR. This runoff flows into DD#17 Pump Station and is pumped over the levee into State Line Outlet Ditch. It has three pumps with a total capacity of 700 cfs. Huxtable Pumping Station is the outlet of 2,013 square mile area and removes impounded interior runoff during high stages along the Mississippi River reach near Helena, AR. It is located southeast of Marianna, AR and discharges into the St. Francis Floodway approximately 13 miles upstream of the Floodway's confluence with the Mississippi River.

Due to high rainfall and effects of the Flood, the pump stations exceeded normal operation periods. Average pumping operations for Huxtable and DD#17 Pumping Stations is approximately 50 and 30 days respectively. During the 2011 Flood, Huxtable Pumping Plant operated for 102 days and DD 17 operated for 30+ days. The stations exceeded the expected operation without any major damage to the structures

c. Yazoo River Area. The Yazoo River Backwater Area is located in Warren and Issaquena Counties, Mississippi, near the confluence of the Yazoo and Mississippi Rivers. It consists of a backwater levee connecting with the frontline Mississippi River levee near Vicksburg and extends along the west bank of the Yazoo River to Yazoo City. Collins Creek Drainage Structure is a gravity drain outlet for the Collins Creek ring levee system that protects several thousand acres of farm land in the Yazoo River flood plain. The Yazoo City Pumping Plant Complex consists of a pump station and a gravity flow section. It contains three 8x8-foot conduits with a total structure capacity of 540 cfs. It is further upstream on the Yazoo River, and gravity drains interior rain water from Yazoo City and surrounding protected areas into the Yazoo River.

During the 2011 Flood, there was backwater up the Yazoo River due to the high stages on the Mississippi River. The Collins Creek Drainage Structure and Yazoo City Pumping Plant Complex were closed on 17 April 2011 and 20 April 2011, respectively; and prevented back waters from entering the protected area. The two structures, however, were not able to gravity drain interior areas that are enclosed by levees. Both structures were closed for approximately 2 months during the 2011 event. The pump station was not operated during the Flood due to lack of rainfall. Because of these drought conditions, there were no impacts due to interior drainage.

d. Lake Chicot Pumping Plant Complex. Lake Chicot, the largest natural lake in Arkansas, is a 16-mile-long oxbow lake created about 400 years ago. During the Flood of 1927, the pattern of drainage was altered and the lake began to fill with silt-laden water. The Flood Control Act of 1968 authorized the Vicksburg District to improve water quality in Lake Chicot through the construction of several structures. The Connerly Bayou Dam regulates water coming into the lake, and the Ditch Bayou Dam maintains the lake at desired levels. The Lake Chicot Pumping Plant Complex is part of the MR&T levee system and diverts water into the Mississippi River from Connerly Bayou when the bayou is turbid with agricultural runoff. Thus, the silted waters go into the Mississippi River, and Lake Chicot is fed only during the winter when Connerly Bayou is relatively clean. When the Mississippi River is low enough, gravity allows Connerly Bayou to flow into the river. The gravity structure contains three 26 feet by 20 feet gates with a max capacity of 10,000 cfs. When the Mississippi River is high, the pumps carry the water over the closed gates of the pumping plant. There are 10 pumps with 600 cfs capacity and 2 pumps with 250 cfs capacity for a total capacity of 6,500 cfs.

The system protected a vast area of agricultural land from flood waters. There was no gravity flow through the Lake Chicot Pumping Plant Complex for most of spring and summer of last year because of high river stages on the Mississippi River. Due to the drought conditions, there was little to no need for pumping during the event. If interior rainfall had occurred during the event, the structure could have been operated to pump excess water into the Mississippi River.

e. Upper Pointe Coupee Parish Loop. Pointe Coupee Drainage Structure (PCDS) is located at the intersection of the Morganza Floodway upper guide levee and Johnson Bayou. The PCDS is ½ mile east of the Atchafalaya River and consists of two motor operated steel lift gates, each 10.5 feet wide and 15.0 feet high. The Pointe Coupee Pumping Station (PCPS) is located on the east bank of the Atchafalaya River approximately 15 miles northwest of New Roads, LA. It consists of an inlet channel, pump-house, discharge piping, outlet structure, and outlet channel. It has three pumps each with a capacity of 500 cfs. The drainage structure, pumping station, and Johnson Bayou are the main components of the drainage system for this area in the northern portion of Pointe Coupee Parish, known as the Upper Pointe Coupee Loop.

Prior to the operation of the Morganza Floodway, the PCDS is required to be closed to prevent water in the floodway from entering the Upper Pointe Coupee Parish Loop. When the PCDS is closed normal internal drainage for approximately 80,000 acres in the Upper Pointe Coupee Loop is cut off. In the event that a rainfall occurred with the PCDS closed, the Corps operates the PCPS to evacuate rain water from the Upper

Pointe Coupee Loop into the Atchafalaya River. During the 2011 Flood, the PCDS operated as intended. The PCDS was closed and no rain fell into the Upper Pointe Coupee Loop. The PCPS was operable although not needed for this event. There were no significant drainage issues to indicate that Johnson Bayou was silted or plugged.

f. Bayou Courtableau Drainage Structure and Darbonne Drainage Structure. The Bayou Courtableau Drainage Structure (BCDS) and Bayou Darbonne Drainage Structure (BDDS) are normally operated to divert rainwater from the landside (Courtableau /Port Barre areas) into the flood side (West Atchafalaya Basin Floodway). The BCDS is located in St. Landry Parish about 1.5 miles southeast of Courtableu, LA. It is a 220-foot long reinforced concrete box frame culvert with five 10 foot wide x 15 foot high water passages. The operating tower, located on the outlet end of the structure, contains five 10-foot, 8 inch x 15-foot, 8 inch hydraulic operated structural steel slide gates. The maximum discharge is 12,000 cfs. The BDDS is located in St. Landry Parish, LA within the West Atchafalaya Basin Protection Levee about one-half mile north of US Highway 190. It is a 10-foot x 20-foot reinforced concrete box culvert with a length of 265 feet and an invert elevation at 6.0 feet mean sea level. The sluice gate is a vertical lift steel gate 10 feet, 8 inches x 10 feet, 8 inches. The drainage structures are approximately 2 miles apart and operate in conjunction. The drainage structures are operated according to the revised Operation & Maintenance guidance letter which dictates that the controlling landside water elevation be maintained at elevation +17.63 feet NGVD during the months of March 1 through November 30, elevation +15.63 feet from December 1 through December 31, and elevation +16.63 feet from January 1 through February 28/29.

During the 2011 Flood, the floodside stages at the structures were higher than the landside stages. The structures operated as intended, and no rain event occurred that would have caused internal flooding on the landside of the drainage structures.

g. Hanson Canal. The Hanson Canal flows from Bayou Teche at Mile 15 to Bayou Portage and is approximately 10 miles west of Calumet along US 90 between Garden City and Franklin, LA. It was originally deepened and widened in the mid 1920's as part of an USACE navigation project that would connect Franklin, LA to the Mermentau River. This project was later superseded by the Gulf Intracoastal Waterway (GIWW) project and thus the Hanson Canal is primarily used for drainage from Bayou Tech and the Franklin area through the Franklin Pump Station. For approximately 8,000 feet—from Bayou Teche to the Franklin Pump Station—the Canal is lined on each side by levees built as part of the West of Atchafalaya Basin project. The Hanson Canal Lock, located at the head of the canal, was abandoned and transferred to St. Mary Parish in 1959.

As a result of operation of the Morganza Floodway, there was concern that backwater effects east of Wax Lake Outlet could raise water levels in the Hanson Canal such that levees along the canal would be overtopped and the surrounding areas would experience flooding. To prevent this flooding scenario, two locations of sheet pile and sand bags were placed by St. Mary Parish across the Hanson Canal as flood fighting measures. To protect from flood waters in Bayou Teche, 76.5 feet of sheet pile was driven immediately north of Highway 90 on 17 May 2011. The sheet pile was driven in the canal to an elevation of ±9 feet using a standard excavator with a vibratory hammer. Work was completed the same day.

Further downstream on the Hanson Canal, near the Centerville Pump Station, 105.6 feet of sheet pile was driven to protect against flood waters entering from the GIWW. Driving began on 18 May 2011 and was completed 19 May 2011. It was done by barge mounted crane with a vibratory hammer to an elevation of ±11 feet. All sheet piles were 45 inches long and tied into the banks on either side using 3,000 pound sand bags. In between the two sheet pile locations, there is a stretch of levees with low crown elevations. Portions of the canal bank were also lined with HESCO baskets for additional stability. The emergency measures were successful in preventing backwater flooding as intended. Pumping for interior drainage from the Hanson Canal was not required due to drought conditions.

h. Franklin Canal. The Franklin Canal carries storm water from Franklin, Louisiana and the surrounding areas to the lower lying areas of the outfall marshes and the Gulf of Mexico. The canal begins within the Franklin city limits, runs southwest, passes under Chatsworth Road and Highway 90 and flows towards the Gulf Intracoastal Waterway. Franklin Canal is lined on the north end by approximately 800 feet of West of Atchafalaya Basin Protection Levees. The levee system runs southeast, crosses the canal at the Chatsworth Road Draw Bridge, turns, and runs north to south. Because the alignment of the canal also turns and runs north to south, the south side of the canal is lined by approximately 10,000 feet of West of Atchafalaya Basin levees. Because of the alignment of the canal and location of the protected areas, there is no levee alignment other than the 800-foot stretch along the northern end of the canal.

Similar to the Hanson Canal, as a result of operation of the Morganza Floodway, there was concern that backwater effects east of Wax Lake Outlet could raise water levels in the Franklin Canal such that the banks of the canal would be overtopped and the surrounding areas would experience flooding. There is no structure across the canal to stop flood waters coming up from the south and the levees on either side stop at the Chatsworth Road Draw Bridge. Flood waters coming up the Franklin Canal would flood the city of Franklin and the surrounding area. To mitigate the effect of the floodwaters, St. Mary Parish installed 128.5' of steel sheet pile with a barge mounted crane and vibratory hammer. Sand bags and HESCO baskets used as a tie- in to the levee system had been placed prior to the sheet pile. Driving began on May 16, 2011 and was completed on May 18, 2011. Sheet pile was 45 inches long length and driven to an elevation of ±11 feet. To allow for drainage and navigation, a 30.16 linear foot section of sheet pile was removed within the canal once flood conditions subsided.

Closing of the canal with sheet pile and other emergency measures was expected to impact the interior drainage for the City of Franklin and the surrounding area. To mitigate the impact and create storage capacity, the protected side of the canal was pumped down approximately 18 inches. A tractor pump was placed on the south side levee near the sheet pile, and interior water was pumped from the protected side of the sheet pile to the flood side. The pumps ran on May 25 and 26 for 18 hours each day. The emergency measure held in place throughout the duration of the event and no additional pumping was required because of drought conditions.

i. Yellow Bayou. Yellow Bayou runs from Cane Road east towards State Route 317down into Thurguson Bayou and eventually flows into the GIWW. Yellow Bayou serves as interior drainage for Centerville, LA and the Centerville Pump Station.

As with the Hanson and Franklin Canals, as a result of operating the Morganza Floodway, there was concern that backwater effects east of Wax Lake Outlet could raise water levels in the Yellow Bayou such that levees along the canal would be overtopped and the surrounding areas would flood. To reduce the flood risk to Centerville, approximately 56.6 feet of sheet pile was driven downstream of Parish Road 16 and upstream of the Centerville Pump Station by St. Mary Parish as a flood fighting measure. A standard excavator and vibratory hammer were used to drive the sheet pile to an elevation of ±8 feet. Driving began on 14 May 2011 and was completed on 15 May 2011. The sheet pile was 45 inches long and tied into the banks of the canal with HESCO baskets and 3,000 pound sand bags. This measure remained in place for the duration of the Flood and performed as intended. No pumping for interior drainage was required because it did not rain.

j. Bayou Chene. Bayou Chene is a large waterway that serves as the main drainage artery for the Lake Verret Watershed. Bayou Chene intersects the Atchafalaya River where the East of Atchafalaya Basin Guide Levee ends. When the Morganza Control Structure is opened, water flows down the floodway and ties into the Atchafalaya River. In major flood event, flood waters exiting at the mouth of the Atchafalaya River back up within Bayou Chene and transport floodwaters into Lake Verret Basin. During the 1973 Flood, this effect in Bayou Chene resulted in backwater flooding within Amelia, Morgan City, Stephensville, Pierre Part, and other local communities east of the Atchafalaya Basin.

Due to the imminent threat of the Flood causing backwater flooding in the Atchafalaya River, on 6 May 2011, St. Mary Parish Levee District (SMLD) submitted a closure plan for Bayou Chene to both the Corps and the Louisiana Office of Coastal Management. On 9 May 2011, an emergency permit was granted, and SMLD began procuring equipment and material for the closure. Construction began on 11 May 11 (photograph IV-12).

Photograph IV-12. Bayou Chene Closure

The closure included 1,000 linear feet of steel sheet pile, 17,000 tons of rip-rap, and the temporary placement, sinking, and mooring in place of a 500-foot long by 120-foot wide deck barge. The water bottom was dredged to a -26.0 ft. (NAVD88) elevation on both ends of the barge. Sheet pile driving operations began on 13 May 11. On 18 May 11, as the sheet pile wall neared completion, the increased water flow and hydraulic forces caused a toe failure of approximately eight pairs of sheet pile. The sheet piles were removed from the channel and on 20 May 11 SMLD requested Corps assistance to close the resulting hole with rock. The Corps responded and placed five barges of 600-pound stone in the failure gap to close the bayou off. Construction was completed 25 May 11.

Aside from the sheet pile failure during placement, the emergency flood fighting measure functioned as intended. By 29 May, the water level crested in Bayou Chene and measured +4.91 feet (NAVD88) on the flood side of the closure and +1.95 feet (NAVD88) on the protected side. No pumping for interior drainage was required because it did not rain. Any rainfall in Amelia or the surrounding area normally drained through Bayou Chene could be drained through the eastern portion of the GIWW. However, some level of pumping would be needed to aid in draining rainfall from the area with the closure in place.

6. Channel Improvements. The Channel Improvement Project on the Mississippi River extends from Head of Passes to RM 956 AHP. The Project is a key element of the MR&T FRM system, maintaining the channel to provide proper alignment and depths for navigation and preventing channel migration to ensure levee integrity. The Project uses a number of features to accomplish its purpose:

Dikes. Dikes are composed primarily of rock placed in the channel and extending into the bank with the crest significantly below top bank to have no effect on highwater stages, but high enough to concentrate relatively low flows in a specified width to provide a self-maintaining channel for navigation. Some dikes are constructed in a "W" configuration with a varying crest elevation to provide some diversity of flow conditions in the vicinity. Photograph IV-13 shows a typical dike field.

Photograph IV-13. Typical Dike

In some areas, dikes are constructed with a notch (figure IV-8) to provide conveyance for flows behind the sandbar at stages below the crest for environmental purposes.

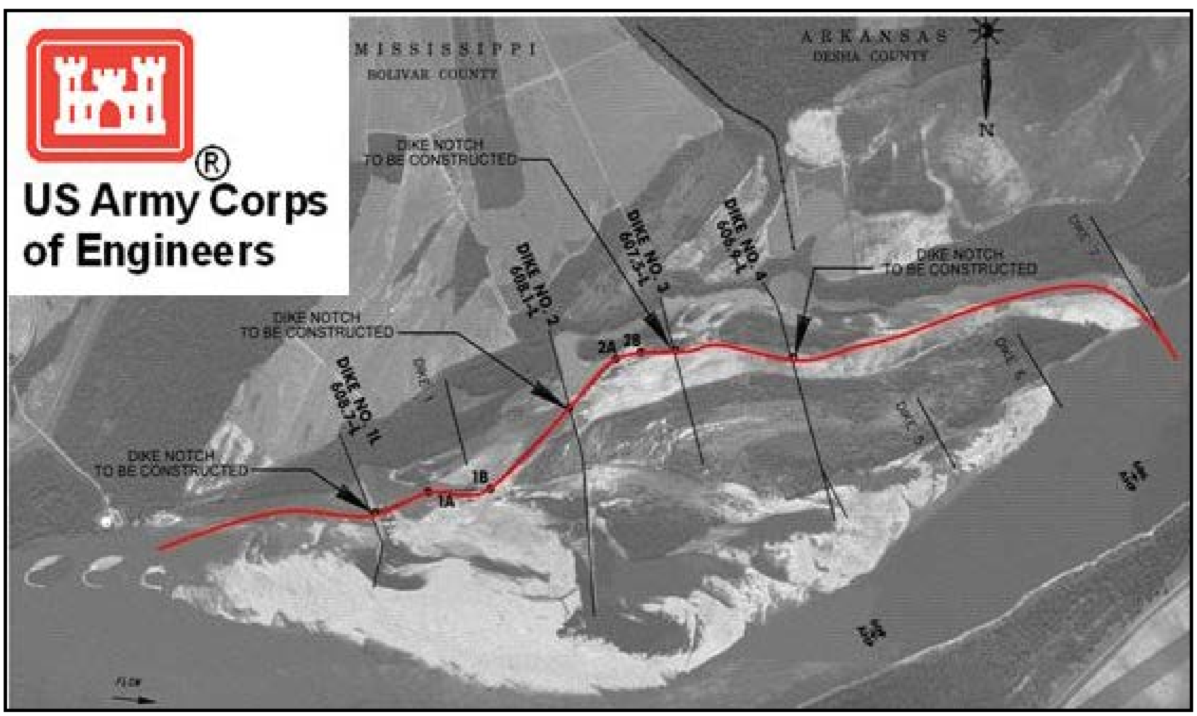


Figure IV-8. System of Notched Dikes

a. Hard Points. Hard points are similar to dikes, but much shorter. In most cases, they have little application for maintaining the low flow channel, but are primarily used to improve channel bank stability in some areas. Typical hard points are shown in photograph IV-14.

Photograph IV-14. Hard Points

b. Chevrons. Chevrons are rock structures constructed in a "U" configuration with the closed end in the upstream direction located a specified distance from the bank. These structures function similar to dikes to concentrate flow in the channel while providing diversity of flow conditions and channel bottom configurations. Typical chevrons are shown in photograph IV-15.

Photograph IV-15. Chevrons

c. Bendway Weirs. Bendway weirs are rock structures constructed in the navigation channel with crest elevations low enough to allow navigation to travel above them. They are angled in the upstream direction from the bank to redirect the flow to provide adequate width for navigation. A schematic example of bendway weirs is shown in figure IV-9.

Figure IV-9. Illustration of Bendway Weirs

d. Articulated Concrete Mattress Revetment (ACM). An ACM revetment is a flexible structure constructed with connected concrete blocks placed on a sloping river bank. The connected blocks are tied to cables that allow the revetment to conform to minor changes in the bank configuration. Upper bank paving composed of riprap is placed on the bank above the concrete blocks. The revetment provides protection from the erosive forces of the river which maintains the bank in its desired location. Prior to placement of the concrete blocks and riprap, the bank is cleared of vegetation and graded for a stable slope to accept the upper bank paving. A typical revetment that has been in operation for a number of years is shown in photograph IV-16.

Photograph IV-16. Revetment

Photograph IV-17 shows an ACM revetment under construction. Note the concrete blocks just above the water surface and the graded bank to accommodate the placement of the upper bank paving.

Photograph IV-17. ACM Revetment Under Construction

e. Use of the Features During the 2011Flood. In the majority of cases, the features of the Project performed as designed. There was damage to some of the individual features, but no catastrophic failures. There were no shifts in channel location and no excessive bank erosion that threatened the integrity of levees. However, there were at least two locations where there was major damage in the form of overbank erosion and, if the duration of the flood had been longer, the river would have very likely changed course and threatened the integrity of nearby levees. One of these locations is at approximate Mile 869.0 at the Merriwether-Cherokee revetment. A private levee overtopped and failed. The resulting crevasse scoured a significant amount of material creating a deep hole. The revetment was damaged but its existence prevented the erosion from being more serious. The other location is at approximate Mile 732.0 at the President's Island revetment. The flood attempted to short circuit the bendway by eroding the overbank area. As at Merriwether-Cherokee, the revetment was damaged but its existence prevented the damage from being much worse.

f. Use of the Features During Non-flood Events. The channel improvement features perform during non-flood flows, as well as, during flood events. The non-flood flows have sufficient forces to erode the channel banks which could have a negative effect on the integrity of the levees and the navigation channel. The dikes contract the non-flood flows to a width and in an alignment that facilitates the development of an efficient navigation channel which also contributes to flood risk management. Each year, approximately 500 million tons of commodities, such as grain and coal, are transported in this channel, making use of the most cost effective and environmentally friendly method of transportation available. The dikes, in conjunction with the articulated concrete mattress revetment, have dramatically reduced the dredging required to maintain the navigation traffic, making the channel essentially self-maintaining. Figure IV-10 indicates the reduction in required dredging as the cumulative length of dike has increased through time. The other features of the channel improvement project (i.e., hard points, chevrons, and bendway weirs) also serve as parts of the system that ensures the integrity of the flood risk management system and navigation channel, both of which are critical to the Nation's economy.

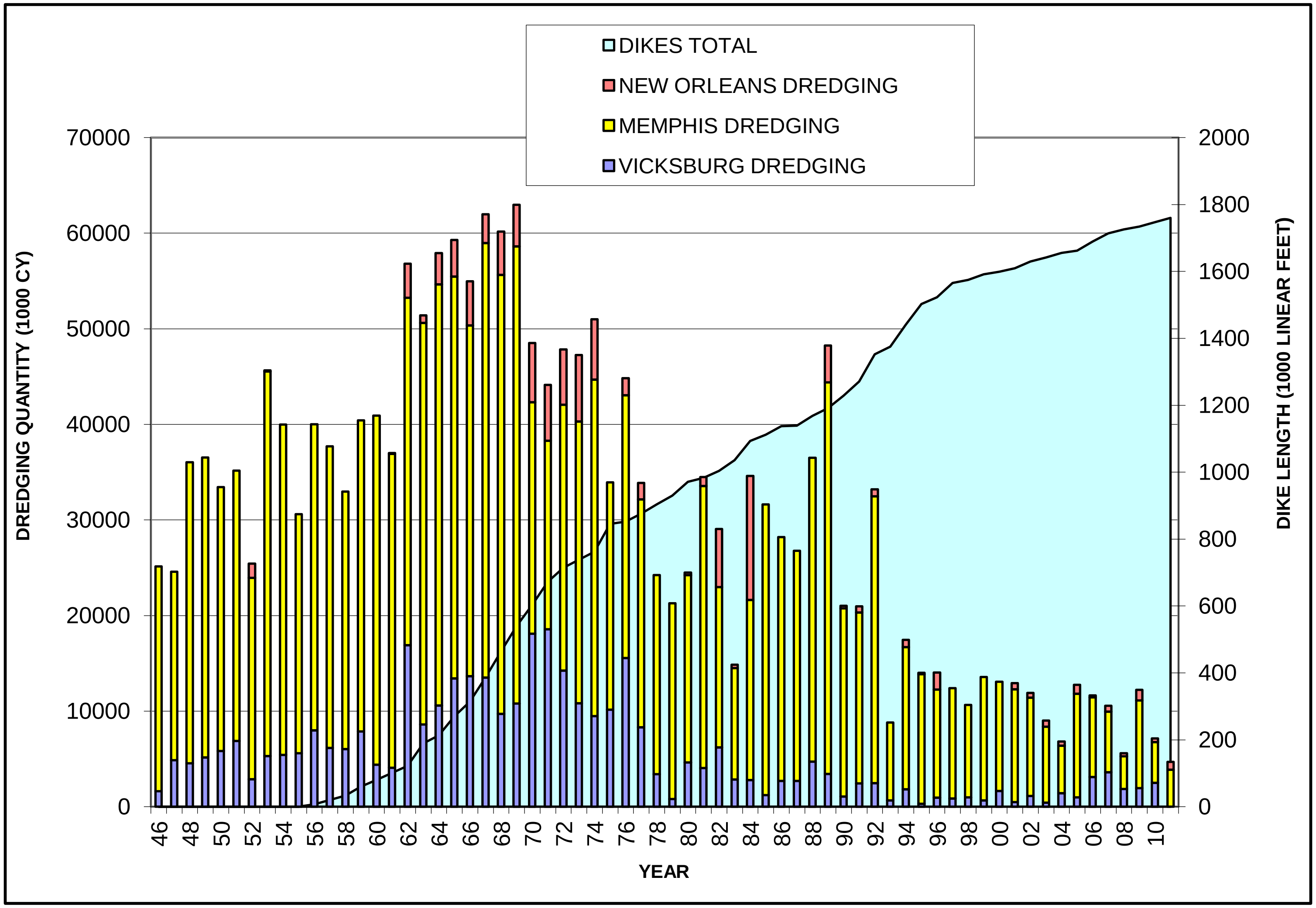


Figure IV-10. Cumulative Dike Lengths and Dredging on Mississippi River

7. Streamflow/Channel Capacity. Table IV-9 shows the locations where flow rates were routinely measured during the 2011 Flood.

In addition to the stream flow measurements identified in table IV-8, measurements were taken at several locations. At the request of the Corps, the USGS collected within channel measurements along the Old River Outflow Channel and Red River Backwater on May 20 and May 26. The idea was to better understand where water enters and exits the overbank areas. Additionally, the Corps measured flow rates on the Mississippi River at the Huey P. Long Bridge to update velocity and depth information and four sets of flow measurements in the Mississippi River above and below Bonnet Carré Spillway, where similar measurements were made in 2008. The Corps also performed measurements on May 28 in the Mississippi River at West Pointe a la Hache, Port Sulphur, Buras, and Empire, in an effort to determine if significant flow was exiting the Bohemia Spillway, located on the LDB of the Mississippi River.

All flow measurements were made with ADCP equipment, with the exception of Morganza Floodway and Bonnet Carre Spillway, where measurements were taken with a Price meter, measuring velocity at 60 percent depth and computing discharge using the mid-section method (referred to as the conventional method). For part of the flood, the Corps performed auxiliary flow measurements at Tarbert Landing using the conventional method. When flow in the Mississippi River at Tarbert Landing exceeds 1,000,000 cfs, the two methods produce different results. The two sets of measurements are taken to better understand the differences in methodology. Because of equipment issues on the discharge boat, it was not possible to make the conventional measurements until May 15, 2011.

Table IV-10 shows the provisional 2011 peak flows along with peak flows from other historic floods in the Mississippi River and the Atchafalaya Basin Floodway System and the PDF flow.

Table IV-9. Locations of Flow Rate Measurements

LMR
Approx Mile 950
Hickman, KY range
Near Tiptonville, TN
Memphis, TN
Helena, AR range
Arkansas City, AR
Greenville, MS
Vicksburg, MS
Natchez, MS
Union Point, MS
Tarbert Landing, MS
Baton Rouge , LA (USGS)
Belle Chasse, LA (USGS)

UMR
Just below I-57 Bridge
Atchafalaya River
Simmesport (Corps and USGS)
Lower Atchafalaya R. @ Morgan City (USGS)
Wax Lake Outlet at Calumet (USGS)
Red River
Madam Lee
Below Lock and Dam No. 1
Black River
Acme

OHIO RIVER
Approximate Mile 961 and 957
Floodways
BPNM - various locations to measure inflow, middle flow, & outflow
Morganza Floodway at Hwy 190 (USGS)
Bonnet Carré Spillway @ Airline Hwy (USGS)
Old River Outflow Channel
Near Knox Landing
Yazoo River
At Redwood

Table IV-10. Project Design Flood, 2011 Flood, and Historic Peak Flood Flows

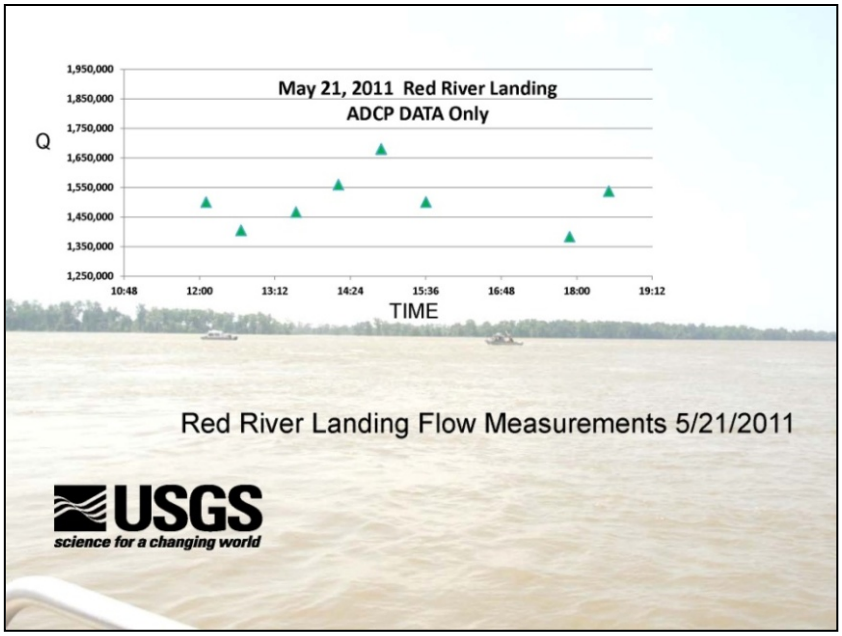
Station	PDF	2011[1]	1927	1937[2]	1973
Cairo, IL[3]	2,360,000	2,100,000 [4,5]	1,626,000	2,010,000 [6]	1,536,000
Memphis, TN	2,410,000	2,213,000	NA	2,020,000	1,633,000
Helena, AR	2,490,000	2,130,000	1,756,000	1,968,000	1,627,000
Arkansas City, AR	2,890,000	2,293,000	1,712,000	2,159,000	1,879,000
Vicksburg, MS	2,710,000	2,320,000	1,806,000	2,060,000	1,962,000
Natchez, MS	2,720,000	2,260,000	NA	2,046,000	2,024,000
Red River Landing, LA	2,100,000	1,641,000	1,461,000	1,467,000	1,498,000
Baton Rouge, LA	1,500,000	1,436,000	NA	1,400,000	1,381,000
New Orleans, LA[7]	1,250,000	1,230,000	1,360,000	1,342,000	1,248,000
Old River Outflow Complex	620,000 [8]	671,000	NA	NA	610,000
Simmesport, LA	930,000	692,000	592,000 [9]	465,000 [10]	781,000
Morgan City, LA[11]	920,000	512,000	741,000	493,000	692,000
Wax Lake Outlet, LA[11]	580,000	323,000	NA	NA	292,000

[1] Provisional Flows, Final flows were being coordinated with USGS at the time this report was produced.
[2] From *Annual Maximum, Minimum, and Mean Discharges of the Mississippi River and Its Outlets and Tributaries to 1963*
[3] Discharge Range at Hickman, KY
[4] Total Confluence flow of 1,936,000 cfs measured at approximate mile 950.8 at 1400 CDT on 5/02/2011 near Wickliffe, KY, prior to operation of BPNM
[5] Peak flow measured on 5/4/11 = 1,730,000 cfs at Hickman plus 370,000 cfs flow through BPNM Floodway
[6] Includes flow through BPNM Floodway
[7] New Orleans Mean Daily Flow as determined from gage at Belle Chasse. Readings at this site are tidally influenced. An instantaneous measurement of 1,320,000 cfs was made on 5/17/11.
[8] ORCC design flow is greater than 620,000 cfs PDF flow and considers a low Red River; current capacity of the Federal structures at ORCC is 740,000 cfs
[9] Source: MVN
[10] Source: Rivergages.com
[11] Wax Lake Outlet was constructed from 1937-1942. Prior to that, Lower Atchafalaya R. was the major outlet.

The USGS measurements in the Morganza Floodway and Bonnet Carre Spillway are taken to verify flow computed by the Corps at the structures. The Morganza Floodway measurement site at Highway 190 is over 17 miles downstream of the Morganza structure. The MVN requested USGS to investigate discharge measurement sites closer to the Morganza structure or where ADCP measurements could be made; because of the distance between the Morganza structure and the USGS measurement site, and the travel time between the two locations, there was some difficulty in correlating the flow measurements with the computed flow. Review of the MVN 1973 PFR revealed that there was some kind of flow measurement taken at the structure; after discussions with retirees, it was determined that a Price meter was dropped in each gate bay, and the measured velocity was used with an estimation of the flow area to get a discharge.

After a site visit, USGS concluded that ADCP measurements on the Mississippi River side were not practical because of complex entrance conditions in the forebay; further, for a safe operation, two boats could be required. USGS found one location in the floodway between the structure and Highway 190 where a measurement could be made, and on May 21, 2011, took an ADCP measurement. The USGS took considerably longer to complete the ADCP measurement at this location than at the Highway 190 site because the speed of the boat must be less than the velocity of the stream; therefore, there was no benefit to relocating the range.

On May 12, 2012, prior to the operation of the Morganza Floodway the discharge measurements at Tarbert Landing showed large divergence from the discharge-stage rating curve for Tarbert Landing and a significant decrease in flow, although the stage had increased 0.7 foot and stages continued to rise upriver. A second measurement was mandated, which was almost 100,000 cfs greater than the measurement taken in the morning and appeared to better represent the flow in the river. It was assumed that there was a problem with the ADCP measurement; however, the same issue arose on May 13, 2011. The ADCP measurement was around 50,000 cfs less than the second measurement taken on May 12 with an increase in stage of 0.4 foot. The Corps began taking ADCP measurements twice a day and continued through June; the Corps enlisted the services of USGS to take additional measurements at Tarbert Landing. USGS crews collected numerous ADCP measurements on May 21-22. Plots of the USGS measurements are shown in figure IV-11.



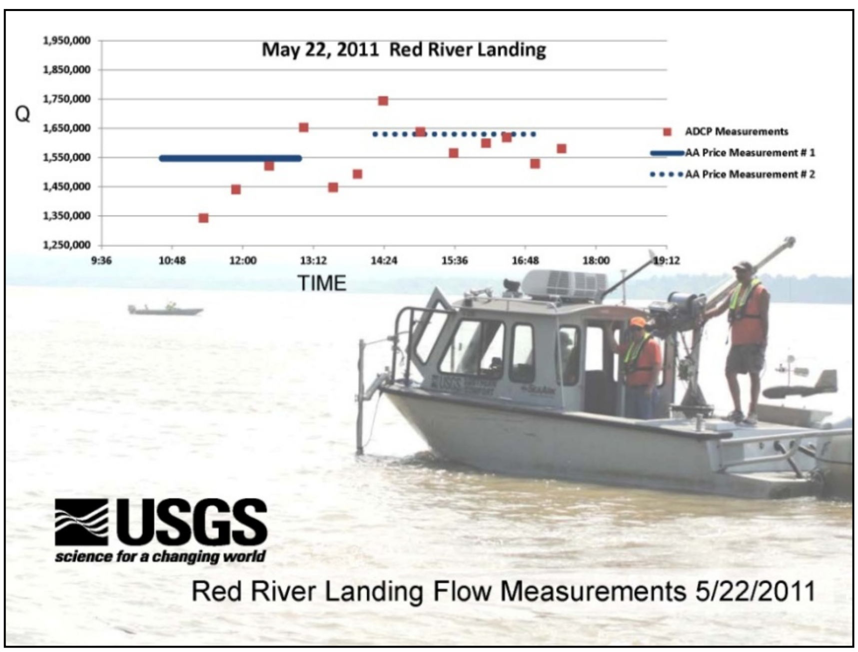


Figure IV-11. Red River Landing Flow Measurements

Additional measurements were taken to provide insight into the difference between ADCP and Price meter measurements on the Mississippi River. Between May 15 and May 30, 12 sets of point measurements were taken in the thalweg of the Mississippi River at Tarbert Landing. One 15-minute ADCP point velocity measurement and 120- and 240-second point velocity samples at 20, 60, and 80 percent depths were taken.

8. Environmental Factors and Cultural Resources

a. Environmental Factors. As the 2011 Flood developed, the environmental and cultural resources specialists assembled interagency teams, kept those teams abreast of new information and developments and set up the protocols and contracts to initiate background monitoring and sampling before the flood affected areas within the watershed.

A list of POCs that were members of the interagency weekly phone calls and the flood response is provided in Appendix A, *Reservoirs*. The list should be updated every 2 years by Emergency Operations personnel.

Environmental data was collected prior to the full impact of flood waters in order to provide a baseline for comparison. Funding and scopes of work were put in place to establish water quality monitoring. During the 2011 Flood, two water quality studies were conducted.

The first was the evaluation of water quality at historically established USGS National Stream Quality Accounting Network sites along the Mississippi and Atchafalaya Rivers. Table IV-11 lists the name and locations of the 15 primary field data collection stations, which were used to measure water quality during the flood period. Figure IV-12 is a map of these stations.

Table IV-11. Water Quality Gaging Stations Along the Mississippi and Atchafalaya Rivers

Station Name	Site #
Mississippi River at Thebes, IL (Upper Mississippi River)	1
Ohio River at Dam 53 Near Grand Chain, IL (Ohio River)	2
Birds Point Levee Breach Inflow (BPNM Floodway)	3
New Madrid Floodway Inflow Outflow No. 2 (BPNM Floodway)	4
Mississippi River at Tiptonville, TN	5
Mississippi River at Memphis, TN	6
Mississippi River above Vicksburg at Mile 438, MS	7
Mississippi River near St. Francisville, LA	8
Atchafalaya River at Melville, LA	9
Atchafalaya Floodway near Ramah, LA North of I-10 F (Morganza Floodway)	10
Mississippi River at Baton Rouge, LA	11
Lower Atchafalaya River at Morgan City, LA	12
Wax Lake Outlet at Calumet, LA	13
Bonnet Carré Spillway at US Hwy 61 near Norco, LA (Bonnet Carré Spillway)	14
Mississippi River at Belle Chasse, LA	15

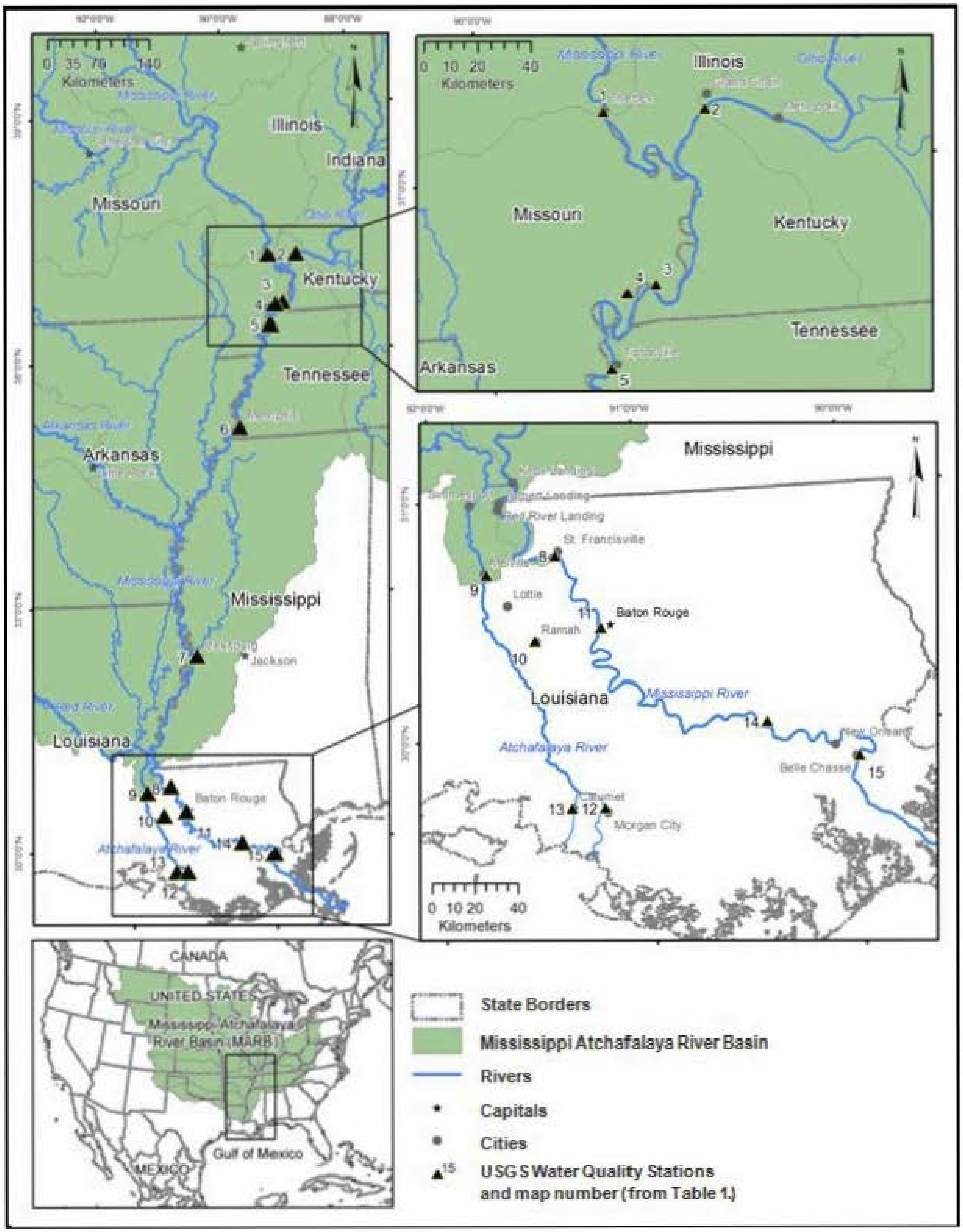


Figure IV-12. Map of LMRV and the Location of the Primary Water Discharge and Quality Measurement Stations (USGS)

A second water quality study focused on the movement of water from the Bonnet Carré Spillway, through Lake Pontchartrain, and into Mississippi Sound. During the 1997 opening of the Spillway, blue-green algae blooms were observed, resulting in the closure of portions of Lake Pontchartrain to recreational activities in order to limit human contact with the potentially toxic algae. There is considerable local interest in the water quality of the lake and interest from local commercial fisherman as the freshwater leaves the lake and enters into Mississippi Sound vicinity.

In order to assemble the data collected from the above efforts, as well as link to data collected by various state agencies, universities and non-governmental organizations, a data viewer was constructed as the flood was developing. The Corps and the USGS have archived water quality data from throughout 2011 Flood in the LMRV and have made it publically available online (http://deltas.usgs.gov/spillway/BonnetCarre2011.aspx; or http://la.water.usgs.gov/MississippiRiverFlood2011.html). A screen capture from the homepage of the data viewer is shown in figure IV-13, which illustrates the geographic extent of the interagency sampling and the range of agencies who participated in the effort.

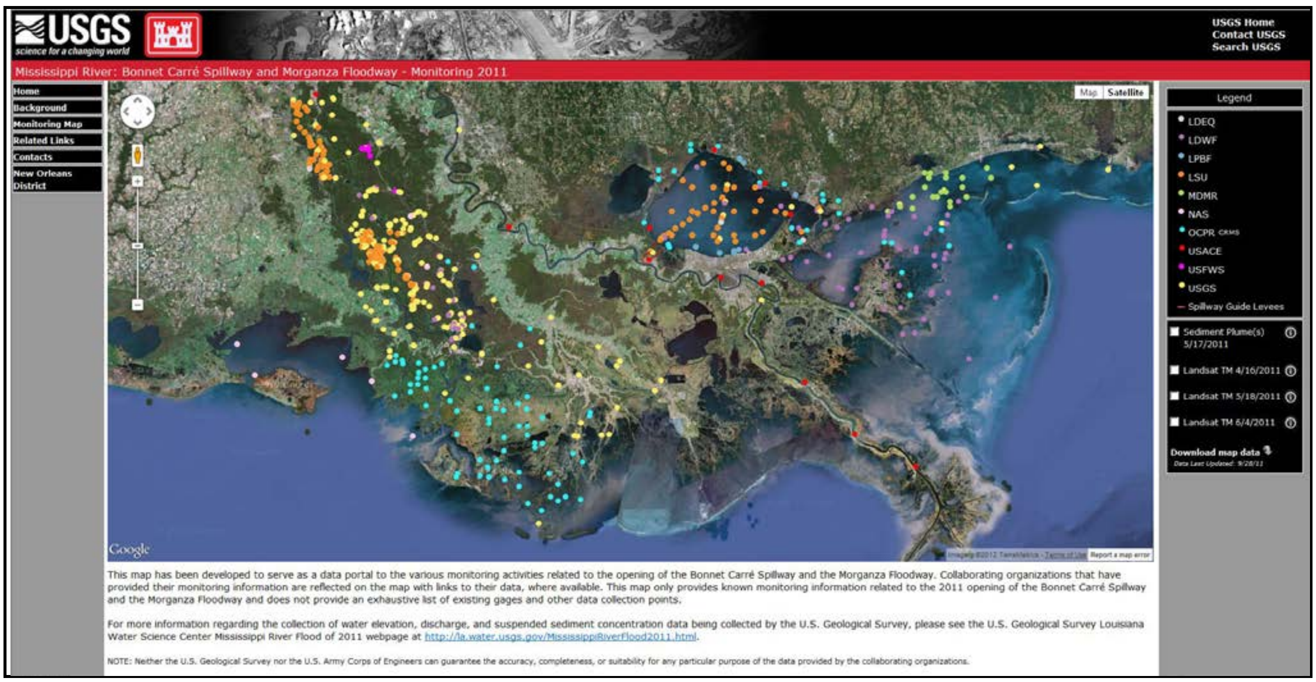


Figure IV-13. Homepage for the Data Viewer Developed by MVN and USGS National Wetlands Research Center During the 2011 Flood to Archive Water Quality Data and Make Available to the Public

b. Cultural Resources. Prior to the activation of the BPNM Floodway, culturally affiliated and federally-recognized tribes were notified of the possibility of activation by telephone and email and then periodically briefed during the activation by follow-up emails and teleconferences. County coroners and sheriffs were advised on the Corps procedures for dealing with inadvertently exposed human remains. Under the revised Missouri statutes (Chapter 194), the Missouri State Historic Preservation Office (MO SHPO) has jurisdiction over human remains associated with prehistoric and historic archaeological sites on non-Federal private lands. In addition, Corps Quality Assurance personnel working on levee restoration were briefed on these procedures and given the telephone numbers and email addresses of the District Archaeologist and Tribal Liaison in the event they made discoveries of human remains. They were advised that if human remains were discovered during the immediate post-flood period, the following actions would be implemented. This would include notification of the respective county coroner and sheriff, the MO SHPO, and the affiliated tribes. The decision to collect exposed remains would not be made without full tribal consultation and monitoring. If the remains came from privately owned lands and were collected by (or turned over to) the MO SHPO, NAGPRA consultation on the final disposition of the remains would be led by the MO SHPO. If the human remains came from lands held in fee status by the MVM, then the MVM would lead the NAGPRA consultation on their final disposition. In all cases, reburial in place should be regarded as the preferred alternative.

Finally, the MVM should begin aerial flights using LiDAR remote sensing as soon as the floodwaters receded and before revegetation/replanting began. This would ensure that all scour areas could be mapped and incorporated in MVM's GIS database. This would enable the District to prepare a detailed damage assessment independent of the landowners' permission to access private land. Similar procedures for the treatment of inadvertently exposed human remain were developed by MVN for the Morganza Spillway and the Bonne Carré Spillway in compliance with Louisiana state law.

9. Forecasting. River stage forecasting provides vital planning and operational information for flood fighters and other people responding to floods. The NWS is the official forecasting agency of the Federal Government. The Corps produces operational forecasts in order to operate our projects and carry out our missions. Before the 2011 Flood, the Corps joined with other Federal agencies to strengthen and improve Federal river stage forecasting. During the Flood, further need for forecasting improvement was identified. The following sections describe river forecasting background and issues.

a. Forecasting Background. River forecasting has played a key role in how society responds to flooding. In some years, forecasting has come under severe criticism, notably during the 2008 UMR Flood and the 2010 Cumberland System Flood. Due to forecasting improvements, the 2011 Flood stands in stark contrast to these two events. However, there were still concerns.

As a result of criticism of the river forecasts before and during the 2008 UMR flood, MG Walsh called for a River Forecasting Summit which was held in St. Louis in October 2008. A major result of this summit was that while the public viewed the Corps operational forecasting as superior, they expected more from the Federal Government's official forecasting agency, the National Weather Service (NWS). The three key agencies—the NWS, the Corps, and the USGS—formed the Fusion Team to improve forecasting capabilities. This team was institutionalized by MG Walsh Commander of MVD; Gary Carter Director, NOAA/NWS Office of Hydrologic Development; and Steven Blanchard, Chief of Surface Water, USGS. The Fusion Team's mission is to improve the accuracy and utility of river/rainfall observations and river forecasts. The team works collaboratively to identify improvements and develop plans to implement them given current science, manpower, and funding constraints. The ultimate goal is to optimize the accuracy and utility of the forecasts provided to the public in accordance with all applicable Federal regulations.

The three agencies that comprise the Fusion Team agree that it has been instrumental in improving the Federal forecast. However, at the time of the 2010 Nashville Flood, many of the same issues were raised and identified as in the 2008 UMR Flood; it became evident that one shortfall of the Fusion Team was its limited geographic scope. Subsequently, the scope of the Fusion Team was expanded to include the Greater Mississippi River Basin.

As indicated in the Spring 2011 Middle & Lower Mississippi River Valley Flood Service Assessment, the forecasting performance was significantly improved from previous floods. It is believed that this can be attributed to several factors:

1. Fusion Team actions
2. HEC-RAS community model for the Ohio River
3. River Forecasters workshop

4. Tri-Agency meeting
5. Increased training of the NWS staff
6. A culture of teamwork among the agencies involved in this Flood

b. Forecasting Issues During the 2011 Flood. While it is generally recognized that the Federal Government, through the NWS, did a much better job of forecasting during the 2011 Flood than during previous floods, multiple users of the river forecasts have pointed out the need for additional improvement. Specifically, there has been a great deal of public confusion about the impacts of the river forecasts as they relate to the operation of the Corps' floodways. The following paragraphs describe areas in which improvements need to be made through coordination /collaboration.

i. Vicksburg District

a. Mississippi River. Based on forecasted rainfall, the crest at the Vicksburg gage was originally predicted to be 52.5 feet on May 13. However, on May 2, the forecasted crest was revised to 57.5 feet on May 18 based on a rainfall event of 3 to 8 inches over northern Arkansas, southern Missouri, and southern Illinois. Due to a collaborative effort between the NWS and Corps, the crest forecasted on May 2 was less than a half foot different than the crest that actually occurred on May 18 (figure IV-14). This is a success story for the flood fighters, decision makers, and others who use these forecasts. There were similar crest revisions along the Mississippi River at all gages inside the Vicksburg District boundaries. The crests at Arkansas City and Natchez gages were both revised upwards by 5 feet, and the crest at Greenville gage was revised upwards by 4.5 feet.

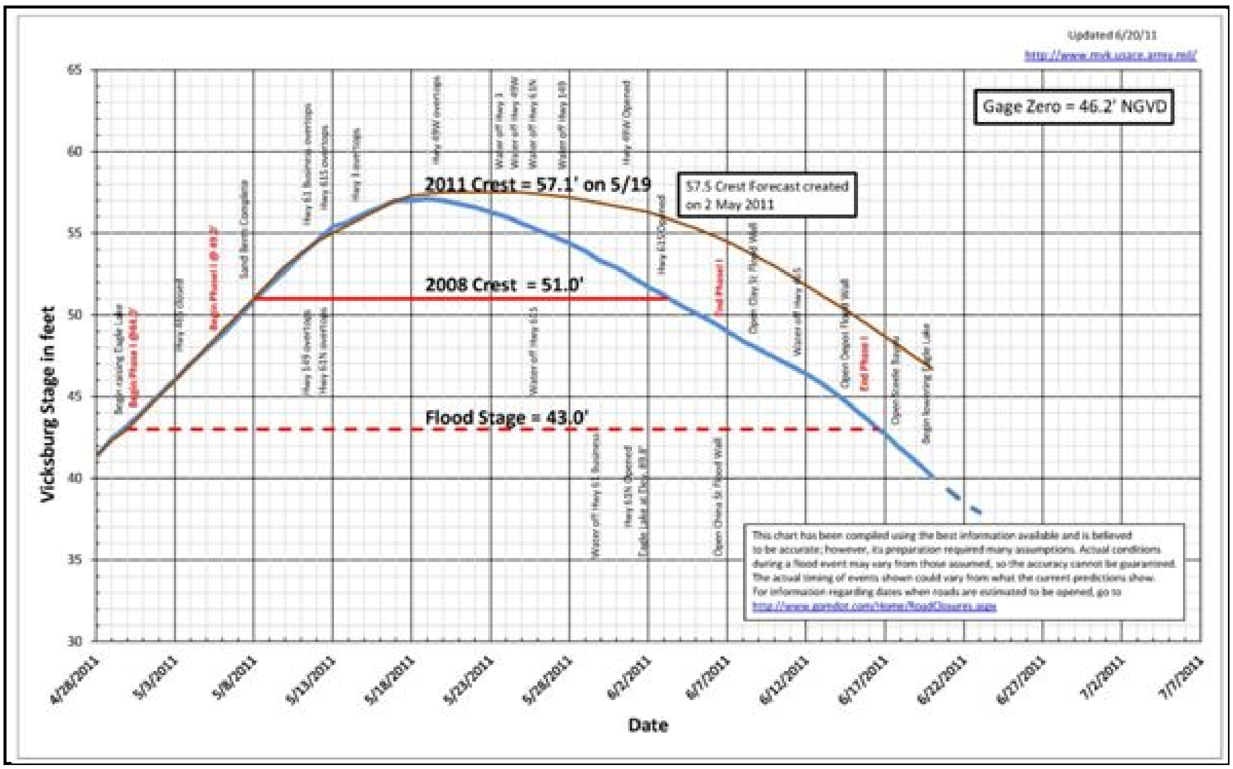


Figure IV-14. 2011 Flood Forecasting Crest for the Mississippi River at Vicksburg
The blue line is the 2011 actual stage; the brown line is the forecasted stage.

b. Red River. The gage at Acme, LA along the Black River is used to determine stages throughout the Red River Backwater area. The gage is located 1/10th of a mile north of the confluence of the Black River and the Red River. From Acme, LA, the Red River flows south into the Atchafalaya River, west of the ORCC.

Based on forecasted crests along the Mississippi River, the forecast crest at Acme, LA was set at 53 feet, 5 feet above the flood stage of 48 feet. The crest prediction was largely due to uncertainty about whether the Morganza Spillway would be operated and whether the watershed would receive normal rainfall. On May 15, the crest was revised to 47 feet, 1 foot below flood stage. The revision was based on the watershed receiving less than normal rainfall which resulted in lower than predicted flows on the Red and Ouachita Rivers, the decision to operate Morganza Spillway and the ORCC diverting less water than planned into the Atchafalaya River Basin. The "over-prediction" of crests caused some public concerns in the unprotected portion of the Red River Backwater area but ultimately did not exceed flood stage.

c. Yazoo Backwater Levee. In order to reduce pressure on the Mississippi River levees during a high water event, the Yazoo Backwater Levee is designed to overtop once floodwaters reach elevation 107 feet. Overtopping was predicted to occur based on crest forecasts. In an effort to prevent erosion of the levee and avoid large repairs after the flood, the Vicksburg District provided erosion protection along the land side of the levee. The actual stages were 0.4 feet lower than forecasted and no levees were overtopped.

ii. New Orleans District. Because the NWS is the official Federal agency responsible for issuing river stage forecasts, MVD's Commanding General instructed MVN to use the official NWS stage forecasts for operation of the MR&T components within the MVN Area of Responsibility (AOR). However, since many of the components—particularly the ORCC, the Morganza Floodway, and the Bonnet Carré Spillway—are operated based on flow rates, MVN staff had to translate the NWS stage forecasts to flow forecasts using stage-discharge rating curves. These curves suffer from known issues such as loop effect or hysteresis[1]. This did not cause a serious challenge until the Morganza Floodway was operated. At that point, further stage rises in the vicinity of Morganza, including at Old River, were dampened by the floodway operation, although flows upriver continued to rise. This impacted stage-discharge relationships and required the use of other techniques to determine flow rates.

c. System-wide Issues. The NWS normally publishes forecasts under the assumption that the Corps will operate water control structures according to approved plans. During the 2011 Flood, the NWS coordinated river forecasts with MVD. Upon request from MVD, NWS published forecasts that did not include Morganza Floodway operation until the MVD Commander made the actual decision to operate the floodway. These forecasts depicted catastrophic stages on the Mississippi River and near-normal stages on the Atchafalaya River. This caused concern in some communities on the Mississippi and may have delayed public preparation for floodway operation along the Atchafalaya River. When flooding first threatened the MVN AOR, the NWS published a forecast showing 17.5 feet at New Orleans. When the NWS contacted MVN to discuss this forecast, MVN told the NWS that their forecast was not likely to be correct, because the

[1] Systems that display loop effect have "memory" that influences how inputs are processed into outputs. In the case of stage-discharge rating curves, a given river stage is associated with one discharge as the river is rising but with a different river stage as the river is falling. This is because as the river is rising, upstream stages are much higher than downstream stages, so the hydraulic grade line is steeper, resulting in higher velocity and therefore higher discharge for a given stage. As the river is falling, upstream stages are still higher than downstream but not by as much; velocities and discharges are correspondingly reduced, even though the river stage is the same. Typical stage-discharge curve show discharge on the x-axis and stage on the y-axis, so rivers tend to "rise on the right" of the overall average curve and "fall on the left." This adds to uncertainty in computing discharge because it's hard to know how much to adjust a curve to account for loop effect when you first receive a discharge measurement - you can only really see it well in hindsight or in actual discharge measurements taken during the event.

Corps would prevent stages from rising to that height by operating the Bonnet Carré Spillway and other features as needed. The NWS subsequently changed the forecast to 17.0 and added a note that it assumed operation of the Bonnet Carré Spillway. Once the decision to operate the Morganza floodway was made, the NWS forecasts included floodway operation. A related circumstance occurred when stages at Cairo, IL approached levels that would trigger operation of the BPNM Floodway and the NWS published a forecast showing 63 feet at Cairo, a level above the trigger that would require operation of the BPNM Floodway and would therefore almost certainly not occur. This situation is different because the stage forecasts affect the decision to operate the BPNM Floodway. The resulting forecasts were both confusing and alarming. They showed unlikely and catastrophic stages in metropolitan Baton Rouge, at the Waterford 3 Nuclear Power Plant, and other locations. This created public communication and public relations issues.

10. Communications/Collaboration. Most communications issues identified during the 2011 Flood were general in nature and applicable to multiple features. Several new technologies presented opportunities to utilize new tools such as Smartphones, and social media sites such as Facebook and Twitter to a greater extent than during previous floods. Although they were not integrated into many pre-flood plans, these tools were generally quickly applied and used successfully to improve internal and external communications during the flood. Field Reconnaissance Emergency Equipment Brokering Operational Assignment Regional Defense (FREEBOARD) and Mobile Information Collection Application software applications were used to efficiently collect and share information more than during any previous floods. Some minor problems were encountered in the field such as poor cell phone reception in some remote areas, a shortage of phones and radios, difficulty in obtaining them, and the fact that few people were trained to use them. However, these problems were overcome and the new field tools were highly successful. Similarly, during and after the Flood, social media were used extensively, with relatively minor problems. Additional details related to the use of these technologies and some of the issues that were encountered are provided in the paragraphs that follow.

Daily communication and collaboration was crucial during the flood. Each District EOC developed a unique Battle Rhythm (table IV-12) to meet its specific communication and collaboration needs.

Table IV-12. Emergency Operations Battle Rhythm

MVS	MVM	MVK	MVN	MVD
0800 • Establish contact w/ flood fight teams • MVD EOC Call • Update to DE via e-mail **1300** Reports from field due to EOC **1400** • DE Brief-MVS flood update • EMA coordination call (when requested) **1600** ENGLink SITREP due	**0800** Area Commander Reports due **1100** Area Coordinator Reports due **1130** Problem Area Map/Material printed **1200** CDR's Briefing Pre-Brief **1230** CDR's Briefing Book updated **1300** CDR's Briefing **1600** SITREPs due **1700** SITREPs available for release **1800** EOC EM Brief	**0700** EOC day shift begins **0800** MVD CDR's Call *Total System Brief* **0830** Field SITREPs due to the EOC **1000** MVD EOC Coordination Call **1100** Change Mgmt Team Staff Briefing **1300** MEMA Coordination Call **1400** GOHSEP Coordination Call **1700** EOC Staff Meeting **1900** Capstone Meeting w/ AAOs	**0700** Internal Daily Briefing **0800** CG Teleconference **0900** MVD EOC call **1300** MVD flood fight supply call **1400** GOHSEP call **1500** Stakeholder teleconference **1900** Freeboard posted/approved **2000** Inventory Report **2100** ENGLink SITREP posted	**0700** EOC day shift begins **0800** MVD CDR's Call *Total System Brief* **0930** EOC Coordination Calls **1000** LRD Update **1300** MVM CMT Briefing **1330** LRD Update **1400** UOC Brief **1500** MVM Birds Point Brief **1600** CMT Brief **1700** CDR's Assessment **1900** EOC Shift Change

MVK's Engineering and Construction, Operations, and Emergency Management branches held a daily meeting at 0800 to coordinate efforts regarding ongoing flood fight projects, which cleared up nearly every communication issue and was overall a great benefit. At the start of the event, there were communication issues among offices regarding the projects. Different offices were reporting different information, and updates were not being communicated to those needing the information. A separate meeting, the Area Commanders Call, was integrated with the Change Management Team (CMT) Staff Briefing. Prior to integration, the Area Commanders briefed the EOC at 1000, and the EOC briefed the CMT at 1100, with the Area Commanders listening in. This change reduced the time the Area Commanders were required for briefings and allowed them to speak directly to the CMT. The CMT Staff Briefing was conducted daily; District personnel provided situation updates and coordinating information to each other and to the MVK Commander. The EOC Staff Meeting was a coordination meeting attended by all EOC members at which EOC leadership addressed administrative issues related to the EOC staff. The Capstone Meeting was a daily update briefing established during this event at which the Area Action Officers provided situation updates to the EOC leadership and the night shift, focusing on high-priority items. The following strengths and weakness were identified in the MVK-AAR regarding internal communication during the Flood:

- The Public Affairs Office (PAO) was receiving great information from the EOC and through the CMT Brief and the AAOs. In particular, the AAOs were an invaluable source of information.
- Coordination between logistics and the EOC was excellent.
- The chain of command was not always used, so employees would take action on behalf of the District without approval and without the proper authority.
- Field offices sent requests for IT support to the EOC, and those requests were not being directed to ACE-IT at the District level.
- It was difficult for the PAO to get access to the pictures that were being sent to the EOC. A plan to set up a share point site for sharing pictures was never completed.
- The PAO was not informed of all public meetings, specifically meetings that were not organized by the Corps and not attended by Public Affairs personnel.
- The Security Office was not informed of all public meetings.
- There was a duplication of effort within the District related to security for the levees. Security began planning for security along the levees only to find out later that another division had begun parallel actions.
- There was confusion regarding the materials being received at the harbor and used for the various projects, specifically information about the timing of shipments of material and which project each shipment was meant for. Overall coordination went well despite some small issues.
- While communication was good throughout the event, it seemed that the District communicated better externally than internally. Throughout the event there were issues with communication between personnel from the field and the District. Some information was reported to either Operations or EOC, but not both. In addition, there was some confusion regarding who had the authority to approve actions in the field.
- MVK's Visitors Center is a poor location to hold a press conference because of the noise from Interstate I-20.

The major communication event to address 2011 Flood activities at MVM was the daily Flood Fight briefing which involved the reporting of all pertinent flood fight activities by each Flood Fight Area/Sector Commander. This briefing was attended by all major staff members, Area Commanders, and MVD supporting team members. The Flood Fight Commander presented major topics and provided an open forum for questions and answers. Major decisions covering a vast array of flood related issues were made and communicated back to the field and stakeholders.

The MVS held daily coordination meetings to communicate with a PDT consisting of the US Coast Guard, the Corps, the railroad industry (Bridges), the River Industry Action Committee, and mariners. This PDT constantly updated and evaluated requests for emergency vessel movements and developed criteria for timely and orderly reopening of the waterways to commercial navigation.

An MVN battle rhythm was established at the onset of the event. Two of the briefings—the internal daily briefing and the stakeholder teleconferences—were hosted by MVN. Initially, the daily briefing included both internal team members and stakeholders. It was determined that it would be more effective to split the calls into one internal briefing in the morning and one stakeholder call in the afternoon. The morning internal briefing included the District Engineer, Chief of Emergency Management, Division Chiefs or their designees, Area Engineers, Project Managers at the structures, and EOC support staff. Afternoon calls consisted of the MVN personnel from the morning and included local levee Districts, parish representatives, and other Federal agencies. Aside from the battle rhythm, technical offices throughout MVN participated in additional teleconferences as they saw fit. The Hydraulics and Hydrology Branch participated in calls with the NWS, and the Environmental Branch participated in calls with the LDWF and other environmental agencies. ENGLink SITREPs were completed and submitted nightly for use at the morning briefings.

One major challenge throughout the division during any flood fight is ensuring that the most up-to-date information is available and used. Floodway operations are no exception. Accessible only by Corps employees, this website consolidated information related to the flood such as supplies, daily briefs, SITREPs, weather, and other information. More education could have been provided to employees; it seemed everyone had a different awareness level and interpretation of data. An organization chart with contact points would be helpful to establish the POC for specific issues.

MVM faced challenges with outdated standard operating procedures (SOPs) and direct access to enough experienced personnel and communications equipment. Internally, MVM lacked the necessary personnel to respond to the large number of significant issues the 2011 Flood presented. Critical communication equipment needed in remote flood fight locations was in short supply and ACE-IT was unable to provide IT support and other logistical items. This prevented positive communications (landline telephone, internet, email, etc.) from being established early in the event.

The existing BPNM Floodway internal SOP and Operations Plan was outdated. Although tools such as ENGLINK were utilized to acquire the staff needed, a clear delineation of releasing authority and approval of information between the Joint Information Center, staff, and USACE HQ was not delineated. Additionally, the BPNM Operation Plan and SOP did not incorporate more recent social media communication tools and capabilities.

After review of the AARs, it appears the ability to communicate was also hampered by the unfamiliarity with the operations and the finite elements of its operation. The Readiness Branch was balancing the BPNM Operation as a part of the 2011 Flood, although the BPNM Operation was not under the direct supervision of the Emergency Manager. This lack of communication resulted in a quasi hierarchy of experience and rank and created some confusion at times on who either had the technical knowledge, experience, or authority to execute specific tasks and decisions.

a. District to District. There was good communication between MVK, the field offices, and the levee boards related to inspection and remediation of the levees. The EOC instituted AAO positions to act as representatives of the respective field offices within the EOC. They were responsible for coordinating information between MVK and the field office and for briefing the EOC staff regarding current hot spots for their areas.

During this event both MVK and the MVN District provided information to the State of Louisiana related to the flood fight. At times this information was contradictory, and at other times one District would provide information that the other would not. There were differences in the information reported by MVK, MVK's field offices, and MVN. There was also inconsistent data reported from the District to the different State and local agencies. For future events the "one door to the Corps" concept should be used, establishing one District as the lead regarding Louisiana. It has been recommended to establish a regional communications plan jointly between MVK and MVN that details what information is reported to various State and local agencies, consider dividing communication responsibilities by State to prevent two Districts from communicating with one State agency, and utilize the Silver Jackets relationships to facilitate communication where possible.

Besides the ongoing communication necessary to address critical items, scheduled teleconference calls occurred on a daily basis with affected district and division offices. These calls were conducted to ensure all participating Corps offices were aware of what was going on upstream and downstream (where applicable) and all operational decisions and their resulting actions and/or adverse impacts could be kept at a minimum. Other transfer of information included river forecasts, precipitation forecasts, and FRM operation decisions.

The reservoir releases in Nashville District (LRN), the LRD, and the TVA affected the stages on the Ohio and Mississippi Rivers. The LRN and the LRD, participated in daily calls with MVM and the Districts and all information was transferred in a positive manner. Similar information as above was transferred. The LRD organizes inter-division and interagency teleconferences to coordinate water management operations and NWS forecasting. These calls were conducted daily, twice a day or more as needed during the Flood. This is part of the long-standing procedure contained in the pamphlet *Regulation of Releases From the Tennessee and Cumberland Rivers During Ohio and Mississippi River Flood Control Operations*.

MVM experienced communication issues with ERDC. Communication between ERDC blasting personnel working on the front-line levee and ERDC personnel at the command/control center was required to coordinate various aspects of the firing train preparation and detonation process. The line of communication between operation sites on the levee and the command/control center was primarily provided by the Corps' boat radio network. Communication during operation of the Inflow Crevasse was also facilitated by direct coordination via down-range vehicle access due to site accessibility. However, communication during operation of Inflow/Outflow #1 (I/O #1) and I/O #2 were solely limited to communications over the boat network (and required a relay from boat to command/control for I/O #1). This severely limited direct communication capabilities between forward ERDC personnel and ERDC personnel at command/control. In some instances communications could not be made. Cell phone communications were also used but were not reliable, particularly for I/O #1 and I/O #2. The remoteness of the crevassing sites limited communication capabilities so that only high-power radio networks such as those on the Corps' boats were functional. For operations at I/O #2, even with the Corps' boat radio network direct communication was not available between personnel on the levee and command/control, so that message relays were required.

Stakeholders in MVM complained of inconsistencies between Districts, primarily relating to inundation mapping standards and the floodway. Some agencies said they heard several different elevations for building back the BPNM levee.

b. District to Division. The MVD "Total System Brief" was a daily conference call at which MVD staff and District Commanders provided situation updates to the Division Commander. See table IV-11 for the scheduled times that these occurred.

Since the operations were related to water resources, a substantial amount of communication was conducted within the hydraulics Community of Practice (CoP) across Districts and divisions. Governing water control instructions, complex hydraulic models, precipitation and river stage forecasts, and available real-time data were examined extensively prior to implementation of major command decisions. As the available information was being reviewed and dissimilated, the Commanders were kept informed of river conditions and the need to act on authorized MR&T Project requirements. These requirements affected reservoir release schedules and Mississippi River floodway operations.

c. Corps to Other Agencies. The Districts within MVD pursued coordination internally and with outside agencies during this event in an effort to synchronize efforts and to share information. Coordination was accomplished in many different ways, including establishing direct liaison with certain agencies, establishing internal and external websites, and participating in recurring meetings and conference calls. During the Flood, Districts within MVD were continuously in contact with the following agencies:

FEMA	State Emergency Management Agencies*
NWS	State Departments of Transportation
USGS	Mississippi Department of Environmental Quality
USEPA	State, County, Local officials in affected communities
US National Guard	Delta Council
US Coast Guard	County / Parish and City Leadership
Local Levee Boards	All disaster agencies/drainage levees in the emergency area

MVK provided liaison officers (LNOs) and MVN provided Local Government Liaisons (LGLs) to various agencies. LNOs and LGLs coordinated efforts between the Districts and their respective agencies, provided information to their agencies, forwarded information requests to the Districts, answered questions, and in some cases provided daily update briefs to their agencies. Agencies with liaisons are denoted with an asterisk in the list above. Agencies in the BPNM area requested liaison officers from relevant Districts be set up with State emergency management agencies. Some local agencies contacted Corps employees that they knew at the District, sometimes in divisions that did not have current flood information.

MVK Water control coordinated very well with the NWS, MDOT, and other agencies. The MDOT provided surveys on roads in some of the areas predicted to be affected by the flood and provided that data to MVK water control, and an overtopping date was predicted using inundation maps. This process worked extremely well during this event and allowed for MDOT to plan for road closures.

From late April to mid June, a daily conference call was held with the NWS, LRD, Southwestern Division (SWD), and MVD. The NWS was provided with the forecast discharges for dams/reservoirs, info on spillway operations and collaborated on individual forecast points. Besides individual calls made to the Divisions and District offices throughout the event and a daily coordination call with all Corps/NWS pertinent personnel on the Mississippi and Ohio River drainage was conducted. Personnel from the following agencies participated:

Ohio River Forecast Center (RFC)	NWS Arkansas Basin RFC
Lower Mississippi RFC	NWS Hydrometeorological Prediction Center
LRN, LRL, LRH, LRP Districts	MVM, MVK, and MVN Districts
SWD, MVD, LRD Divisions	

Three State EMAs requested the physical presence of Corps personnel in an effort to streamline the transfer of information. MVM did not have the manpower to dispatch a liaison to the state emergency management agencies. To assist and accommodate the State EMAs requests, Corps personnel from supporting Districts were dispatched to the requesting agencies. Although, the recruited Corps personnel were not extremely knowledgeable of the area, District personnel or District processes, their familiarity with Corps emergency processes was considered an asset.

The Tennessee Emergency Management Agency (TNEMA) had a daily call with the Corps represented by the MVM and LRN Districts. Others on the call were TVA, NWS, the State of Kentucky and other local governments. As stated above, TNEMA requested a Corps liaison so an employee from the MVN was posted in the Nashville office.

MVS water control staff conducted numerous daily conference calls that provided for situational awareness and information exchange between peers and with interest groups. This process continues during non-flood events, but increased in frequency and intensity as necessary throughout the event. This resulted in the best possible forecast information and opportunities to discuss alternatives (such as deviations) for decisions with other key stakeholders. The MVS AAR recommended that MVS Water Control staff continue to play active role in maintaining and improving interagency cooperation and collaboration.

The following issues were identified through District AARs and post-flood public meetings:

- Many concerns associated with Corps actions in the activation/operation of floodways were identified:
    - decision-making
    - sharing Operation Plans
    - explanation of the procedures
    - open communication.
- There were concerns as to whether the NWS or the Corps had the lead in forecasts.
- Some stakeholders (e.g., levee boards) felt they were neglected as partners—not receiving information, not a partner in decision-making, etc.
- There are some issues with publicizing Operation Plans so impacted parties are in-the-know.
- In some instances, NWS Forecasts assumed that structures would not be operated according to plan, making communication about potential Floodway operations difficult. In some cases more forecast points would also have been helpful.
- Both MVN and MVK had a liaison at LA GOHSEP, but there was inconsistency between the two Districts. There were briefings where Districts reported separately and had different maps, briefs, etc.
- One major deficiency among MVN, EOC, and local government agencies was proper coordination of directives. All directives/instructions should be channeled through the EOC to insure proper funding, communications, and documentation.

There is a need for trained employees capable of performing as District, MVD, or Corps LNOs for other agencies or Districts. During the Flood, MVS provided LNOs to multiple locations in MO and IL, representing both MVS and the Corps in all cases. MVN deployed a team of trained LGLs to various parishes to help the EOC, partner agencies, and communities. Establishing a small cadre of trained personnel that can be used to fill LNO positions at States, or a yearly visit or call in, could benefit future flood fight efforts. MVS (and other Districts) need to maintain contact with LNOs and LGLs and keep them informed to ensure they can adequately represent the District and Corps. In MVS, Silver Jackets are the best candidates. It would be helpful to expand the pool of potential LNOs and LGLs and train prior to next event. These staff need to be provided with District tools and ensured they are included in necessary briefings/updates to remain fully informed.

A majority of communication issues revolved around the activation of the BPNM Floodway and MVM. While most agencies in the area have had successful working relationships with the Corps in the past, several agencies felt as if they were not treated as a partner during the flood and have not heard anything from the Corps since the operation of the floodway. Most stakeholders in the region stated they heard the news about the BPNM Floodway operation on television, despite needing to know the information critical to their operations. Some agencies did not think there was enough vetting of the impacts of the operation.

There were several instances in which agencies needed information from the Corps that they did not receive. Several sources pointed out that they acted on what they saw on TV and never received any information about the operation of the BPNM Floodway from the Corps, not even a phone call. The Governor made decisions based on the reliability of the Corps' information, but there was also a lack of communication and information shared between the State and the Corps. The State asked the Corps many questions, and basic answers took too long to get. Several levee boards/Districts and other agencies felt the Corps was withholding information, particularly in regards to the BPNM Floodway operations.

Information provided to the USCG during the pre-mission planning stage was minimal, including maps of the floodway, predictions of flooding should the mission be aborted, timing and sequence of events, locations for mooring, berthing barge, clearly defined missions of moving safety zone vs security zone on site, etc. Early on in the flood the USCG received conflicting information in regards to expected actions and unclear requirements from the multiple Corps sources that resulted in confusion during the operation. The USCG needed more specific information on what areas of the river were to be closed, how long they would need to be closed before the normalizing, and data showing it was safe to reopen the river by use of the requested survey data. These communication issues between the USCG and Corps were resolved as the flood progressed. Range of radios and cell phones were limited, creating communication problems with the vessel escorts when, due to extreme weather or debris in the water, distance between the escorts and M/V increased beyond the scope of the radios.

Agencies in the region preferred briefings from the Colonel; Colonel Reichling (MVM) was highly commended by the local stakeholders. In some instance however, stakeholders felt the Corps was insensitive and unclear in their briefings, failing to answer the public's questions.

d. Corps to the Public. Several different forms of communication were used to provide information to the public during the flood. Multiple websites were established during this event by the Districts within MVD in an effort to ensure communication and provide information to the public. The result was a series of websites that provided correct and timely information in a consolidated location and allowed for an open dialogue with the public regarding the flood fight. These websites included links to press releases, inundation maps, and other public information.

Social media sites (Facebook, Twitter, and YouTube) were utilized in similar ways during the event. Facebook and Twitter were used to share photographs, link to press releases, and provide opportunities for open dialogue with the public. YouTube was a venue for sharing videos related to the flood fight. This was very effective in correcting rumors and incorrect information, and for informing the public about the flood. Most notably at Wappapello, the use ofFacebook allowed MVS the opportunity to clarify/correct misinformation and be responsive to questions.

The use of social media sites provided challenges. The MVS PAO Social Media Operator eventually moved into the EOC to be able to timely respond to discussion. This was distracting to some EOC staff. It might be possible or preferable to have Subject Matter Experts actually engaged in the discussion rather than PAO if most of the conversation is confirming information. Additional challenges included manning the social media sites since they are 24/7 accessible and their value relies on responsiveness. Ideally, POC and EOC will coordinate social media planning prior to an event and non-PAO employees will be trained on social media operations.

All communication to the media were conducted through the PAO. Within MVM, the PAO was stationed at the EOC and also set up a Joint Information Center at Sikeston, Missouri near the site of the BPNM Operation. The MVM PAO had responsibility for setting up a Joint Information Center and providing all media and journalism support to the BPNM Floodway Operation.

Throughout this event the Districts participated in many meeting with the public, in order to convey information to the public about the flood and the Districts' response, to answer questions from the public, and to dispel rumors and correct false information. They typically took one of three forms: hosted by the Districts; meetings hosted by a state or local agency and attended by the Districts; and meetings called by state agencies or Congresspersons and were generally briefings to emergency response organizations. Many local, state, and Federal agencies were represented at these meetings, and usually all of the agencies would meet prior to the public event in order to share information and coordinate the presentation. The Districts were often involved with planning and organizing the meetings including details such as selecting a location, releasing a public notice about the meeting, and providing presentation materials like podiums and microphones. When possible each meeting was attended by at least three representatives from the related District: a Program Manager (PM), a hydraulics engineer, and a PAO specialist.

In some cases within MVD, the PAO was not aware of public meetings not sponsored by the Corps, which led to some confusion and a lack of coordinated effort. Security was also not informed of some of the meetings and therefore could not ensure adequate security. Additionally, some of the meetings did not have a local sponsor, and due to some coordination issues led to the PAO or Programs and Project Management Division organizing the meeting at the last minute. When a public meeting is identified that will have Corps representation, both PAO and Security should be notified.

MVM used a Staff Action Command Officer who was located in the EOC to address all District incoming "Request For Information" items. Numerous inquiries are processed via the telephone. From the SACO, an Action Officer within the MVM is assigned the "Request For Information" and it is tracked until the response is closed out. It appears the use of the Staff Action Command Officer was extremely productive. First, it ensured stakeholders and customers responses were accurately captured since he was a frontline communicator. Second, it assigned one person the responsibility to seek the proper subject matter expert to address/assess the question. Third, it ensured the action item would be completed by producing a sole employee the responsibility to close the request out.

MVM also used a Sector Area Commander as the first line source of communication to the flood fight area for the public. This process worked well for MVM, but may not be feasible for other Districts where the Sector Area Commander's time is fully committed to coordinating flood fight activities. In these cases, senior staff or PAOs commonly lead the public communication effort. For MVM, major communication was able to occur between the Corps response team and the public at the Sector Area Commander level. Since this was the first line of communication it was probably considered the most reliable because it eliminated the error that is inherent with the transfer of information through a chain of different parties. The Sector Area Commander communicates with the sponsors and stakeholders on a daily basis during the flood fight.

The release of inaccurate or unapproved information to the public was an issue during the 2011 Flood. Most incidents were the result of associates, friends, and/or family seeking inside information about flood conditions. This resulted in some individuals being reprimanded, however a more effective solution has not been implemented. Many residents and communities do not understand how the MR&T is designed to work. As partners, the Corps needs to better educate the public. Not all residents (e.g., Red River backwater area in MVN District) understand how data is reported (i.e., gages vs. stages). Additionally, the public wanted consistency and timeliness in reporting.

11. MR&T System-wide Summary of Operational Performance. The components utilized to manage floodwaters during the 2011 Flood included upstream reservoirs, levees, floodways, backwater areas, and pumping stations. These individual components were operated as a system to reduce and balance overall flood risks as the flood moved through the LMRV. The design and operational strategy for the MR&T System does not entirely exclude the river from its natural floodplain. Instead, at key locations, it accommodates the natural tendency of the river during extraordinary events like the 2011 Flood by incorporating floodway and backwater features that are only utilized during rare and extreme events. For the first time in the MR&T project's history, the BPNM and Morganza Floodways and the Bonnet Carré Spillway were placed in simultaneous operation to relieve the enormous and sustained stress on the levee system.

Emergency flood fight measures were required to pass the 2011 Flood. These measures included ringing sand boils, constructing water berms, blocking culverts/ditches to impound surface waters, constructing erosion control measures, and raising the level of protection in some areas. Although significant flood fight measures were required, the vast majority of the flood fighting efforts were concentrated at weak points that had been identified prior to the 2011 Flood because they were either incomplete features of the MR&T System or areas that experienced issues during previous floods.

Leadership at each District aggressively pursued coordination internally and with outside agencies in an effort to synchronize efforts and to share information. Coordination was accomplished in many different ways, including establishing direct liaison with certain agencies, establishing internal and external websites, using social media to inform the public, and participating in recurring meetings and conference calls.

During the 2011 Flood, the MR&T System successfully performed as it was designed to and the Corps executed its responsibility to support local interests in all phases of flood fighting. However, the 2011 Flood caused significant economic, environmental and structural damages and exposed vulnerabilities in weak and incomplete portions of MR&T System components. It also tested and identified deficiencies in some Emergency Action, Operations, Communication, Water Control, and other pre-flood planning and process documents, and decision-making tools like no flood before had. An analysis of key operational decisions related to the operation of the MR&T System follows in the next section. Details related to economic and environmental damages resulting from the 2011 Flood are presented in Section V. An analysis of the flood's impact on MR&T System components, the damage assessment process, and the repairs that are needed to prepare the MR&T System for future floods are presented in Section VI.

E. KEY OPERATIONAL DECISIONS

Many decisions related to the operation of the MR&T System were made throughout the 2011 Flood. MR&T components are operated as a system to minimize and balance overall risk to lives, property, and the nation's resources. Individual MR&T components are operated and protected during a flood based on operating plans, standard flood fight procedures, and past experience. These processes, along with information on existing and forecasted conditions, guided and supported significant operational decisions as flood waters moved through the MR&T System. Four MR&T components—BPNM Floodway, Muddy Bayou Control Structure, Yazoo Backwater Levee, and Morganza Floodway—and supporting information provide details on complex situations that required key operational decisions during the 2011 Flood. Most of the details presented here were captured through interviews and review of District reports and are further described in the 2012 MRC document, *Divine Providence – The 2011 Flood in the Mississippi River & Tributaries Project*. Section IV. D. of this report also provides additional information on emergency activities conducted at these and other MR&T component locations.

1. Birds Point-New Madrid Floodway

a. Key Decision. Operating the BPNM Floodway

b. Background. The BPNM Floodway is located in southeast Missouri along the west bank of the Mississippi River just below the confluence of the Mississippi and Ohio Rivers. It is designed to be operated at or near specific conditions to pass extreme floods that would otherwise exceed the system's capacity. Prior to 2011, the Floodway had been operated only once before during severe flooding in 1937. The Floodway is operated by detonating explosives within fuseplug pipes installed in three sections of the frontline river levee. The explosives create crevasses to divert up to 550,000 cfs from the Mississippi River through the Floodway. When operated, the Floodway inundates about 130,000 acres along the west flank of the Mississippi River for which the Corps has flowage easements. Operating the Floodway lowers the flood stage by up to 7 feet near Cairo, IL (with smaller stage reductions along the Floodway reach south of Cairo) and lowers the risk of a catastrophic failure or overtopping of mainline levees protecting much larger and more populated areas along the Mississippi River. Section IV.D.3 of this report provides additional details on the BPNM Floodway.

c. Operating Plan. Based on the BPNM design and 1986 Operating Plan, the Floodway normally will not be operated until flood stages in excess of 60 feet are predicted on the Mississippi River gage at Cairo, IL. At approximately 60 feet on the Cairo gage, the upper fuseplug section will be completely prepared for operation. Preparation of the lower fuseplug section follows operation of the upper fuseplug section. Generally, an activation stage of 61 feet on the Cairo gage (with additional stage increases in the forecast) is used by the MRC in operating the Floodway. See the MRC Information Paper *The MR&T Project: Birds Point-New Madrid Floodway*. The BPNM Operating Plan also allows for operating the Floodway sooner (at 58 feet on the Cairo gage) if the levee system is considered to be in danger of failing. Operating the Floodway utilizes existing equipment and approximately 150 MVM personnel, as well as equipment, explosives, and other materials that need to be obtained specifically for the operation.

d. Primary Issue at Hand. Operating the Floodway requires evacuating 230 residents and explosively removing the crevasse portions of the frontline levee, which would then need to be repaired after the flood. Operation would also inundate homes and structures and increase the level of flooding in up to 130,000 acres of productive agricultural land. Not operating the Floodway could result in other mainline levees overtopping or failing with much more significant damages and potential loss of life. Early forecasts put the peak flood stage very close to the Floodway activation stage. In the days leading up to the decision, some decision makers believed it possible to pass the 2011 Flood without operating the Floodway and avoid the associated damages, as rates of rise in river levels were gradually slowing. However, significant additional rainfall occurred on 30 April through 2 May, accelerating rates of rise in stages and causing forecasted stages to exceed 61 feet at Cairo. This late change in conditions resulted in the decision to operate the Floodway.

e The Operational Decision. Preparation for operating the BPNM Floodway was initiated on April 25, 2011 with the loading of barges with materials, equipment, and personnel at Ensley Engineer Yard and culminating with operating the Floodway on May 2, 2011, resulting in successful passage of flood waters through this constricted reach of the Mississippi River. Many factors were considered in making this key operational decision, the most prominent of which included the Floodway operating plan; actual and forecasted flood crests at Cairo, IL; potential damages caused by operating the Floodway and the effects on future MR&T System performance; significant precipitation and saturated hydraulic conditions throughout the Basin; use of all available reservoir storage capacity to influence the flood crest at Cairo; deteriorating conditions of MR&T levees near Cairo, IL and in Fulton County, KY; and the time needed to prepare the Floodway for operation. Severe local weather conditions also influenced the timing of preparation and operation efforts, resulting in the Floodway activation occurring at a stage of 61.72 feet on the Cairo gage. The following detailed information lays out how MVD and MVM made the key operational decision to operate the BPNM Floodway.

Birds Point-New Madrid Floodway

April 20, 2011 (Wednesday)

- Cairo gage exceeds 49 feet
- MVM enters Phase I flood fight in Cairo, Missouri and Reelfoot-Obion areas (for second time this year)

April 21, 2011 (Thursday)

0600: Cairo gage reaches 49.8 feet, NWS forecasted crest is 52 feet on 30 Apr

- NWS contingency forecast (worst-case scenario) calls for 61.1 feet flood crest at the Cairo gage on May 3 or 4
- MRC, MVM, MVD and LRD Commanders are notified of the situation

April 22, 2011 (Friday)

0600: Cairo gage at 50.3, forecasted crest is 52 feet on 30 Apr

- Heavy rains currently falling throughout Mississippi and Ohio River basins will continue to fall over coming days based on NWS forecasts
- LRD increases discharges through Kentucky and Barkley dams to clear additional storage space for upcoming forecasted storms

April 23, 2011 (Saturday)

0600: Cairo gage at 51.0 feet, forecasted crest is 52 feet on 30 Apr

- Significant rainfall continues through the middle Mississippi River Valley

April 24, 2011 (Sunday)

0600: Cairo gage at 52.4 feet, NWS revises projected crest at Cairo to 58.5 feet on 3 May

- MVM enters Phase II flood fight in Cairo, Missouri and Reelfoot-Obion areas
- System-wide flood storage utilization by reservoirs stands at 15%
- Heavy rainfall continues and begins rapidly filling reservoirs
- LRD Div CDR directs LRD District Commanders and senior leaders that flood duty missions take top priority and offices must make all efforts to reduce max. crest at Cairo

April 25, 2011 (Monday)

0600: Cairo gage at 54.5 feet, NWS revises projected crest at Cairo to 60 feet on 3 May

- NWS forecasts another 8 inches of rain for the area over next 3 days
- Small sand boils begin to form across the confluence area, especially in the Cairo, IL and Fulton County, KY sectors
- County Sheriffs order 230 residents within the BPNM Floodway to evacuate
- MVM CDR, following operating plan, orders crews to move forward with loading barges with explosive materials
- LRD begins holding water in reservoirs currently under repair within the Cumberland system after assessing integrity risks
- State of Missouri files suit in the Eastern District Court of Missouri seeking a temporary restraining order to halt the Floodway activation

April 26, 2011 (Tuesday)

0600: Cairo gage at 56.5 feet, NWS revises projected crest to 61 feet on 3 May

- Intense rainfall continues in the confluence area
- Flood fight operations underway throughout the confluence area
- MVD CDR orders movement of barges carrying explosives to a harbor in Hickman, KY and land-based crews to depart on April 27 at 7:30 to begin access well preparations.

Birds Point-New Madrid Floodway

April 27, 2011 (Wednesday)

0600: Cairo gage at 57.9 feet, NWS revises projected crest to 60.5 feet on 1 May

- Forecast calls for rain today and then 2 days of dry weather
- Corps and MRC senior leaders conduct site visit at Birds Point mainstem levee. The following information that was provided for BPNM operational decision making should be assessed for accuracy and added to the floodway operations plan for future decision making on the floodway. MVD CDR and MRC were informed of difficulty of removing explosive material from fuseplug pipes if not detonated. Filling fuseplug levees w/ explosive slurry does not commit MVD CDR and MRC to operate the Floodway, but it would be very complicated and time consuming to remove the material; residents would not be allowed to return to their homes for weeks, maybe months after flood season ends. Commercial navigation may also need to shut down during material removal.

April 28, 2011 (Thursday)

0600: Cairo gage at 58.7 feet, forecasted crest 60.5 feet on 1 May

- No significant rainfall, but forecast calls for additional rain coming 30 Apr to 1 May
- LRD proceeds with storing water in Kentucky and Barkley Lakes and also increases storage in Cumberland system reservoirs. LRD's primary goal is to hold water back long enough to give MVD enough time to load the fuseplug pipes (filling the fuseplug pipes takes approx 18 hours)
- LRD CDR sends e-mail to MVD CDR recommending MVD start filling the fuseplug pipes at the inflow crevasse as soon as possible
- Concern raised about the integrity of the Fulton County, KY levees with large number of sand boils developing
- MVM CDR informs MVD CDR that although the operating manual allows activation of the Floodway at 58 feet on the Cairo gage if levee system is near failure, current conditions at the Fulton County levee did not warrant activation
- MVM CDR recommends holding the barges at Hickman harbor for now and MVD CDR concurs
- MVM discovers high energy sand boil near Cairo, IL in the evening; proceeds with flood fight measures involving building 10 ft high berm around boil
- To address hundreds of sand boils along Fulton County levee, MVM staff constructs 1,500 ft rock berm perpendicular to the levee and cover the boils with a blanket of water

April 29, 2011 (Friday)

0600: Cairo gage at 59.0, forecasted crest 60.5 feet on 1 May

- Weather forecast is for 1.5 to 5 inches of rain over the next 5 days
- Two additional high energy sand boils discovered and addressed near Cairo
- Cairo Mayor issues a voluntary evacuation of the City
- Eastern District Court of Missouri denies State of Missouri's temporary restraining order request to halt activation

April 30, 2011 (Saturday)

0600: Cairo gage at 59.1, NWS revises projected crest to 60.5 feet on 3 May

- Heavy rains begin again in the area, weather forecast calls for 7.5 inches of additional rainfall over Ohio River valley through 2 May
- Due to increased rainfall, LRD increases releases from Kentucky and Barkley dams to stabilize the reservoirs
- Pressure of significant flood water on the mainline levees continues to cause numerous underseepage and sand boil issues
- Landowners complete mandatory evacuation of the Floodway
- MVM CDR recommends H minus 21 (position barges on Floodway frontline levee and hold)
- MVD CDR orders barges to Wickliffe, KY (3 hours closer to operational timeline)
- Cairo, IL proceeds with mandatory evacuation
- Eighth Circuit Court of Appeals denies State of Missouri's appeal to the decision

Birds Point-New Madrid Floodway

May 1, 2011 (Sunday)

0600: Cairo gage at 59.69, NWS revises projected crest to 61.5 feet on 5 May

- Heavy rains continue to push gage higher at Cairo

1000: Col Reichling briefs MVD CDR and MRC on conditions and advises going to hour minus 3 in the BPNM Operating Plan (move barges into position, load pipes with explosive agents, and hold). MVM CDR explains that safety plan calls for crews to be off levee by the time the Cairo gage reached 60.5 ft and based on the current forecast they needed to move soon to make this happen

- MVD CDR orders barges to the levee at Birds Point and asks to be briefed again at 1500 hours
- Significant flood fight activities continue through the Cairo and Fulton County area
- Robert Fitzgerald, MVD Chief of Eng. provides assessment to MVD CDR that the Corps could manage flows under current conditions, but the system is weakening

1500: MVD CDR and MRC briefed on current conditions: Cairo gage 59.93 ft and rising at 1400; would reach 60.5 ft by late a.m. 2 May. NWS forecasted crest now at 61.8 ft on 4 May and expects river to remain above 60 ft for 9 days and 61 ft for 5 days; NWS concerned that heavy rains could cause river stages to spike; LRD reports they may need to increase water releases soon from reservoirs should the heavy rains continue. Cairo and Fulton County levee systems under tremendous stress but holding with intense flood fight measures. Safety of work crews requires completion of 18-hr fuseplug prep prior to 60.5 -ft stage. Col Reichling, MRC, and MVD Sr Leaders recommend going to hour minus 3

- MVD CDR approves going to hour minus 3
- Barges move into position on frontline levee to begin pumping slurry

1930: Crews on hold to load pipes w/ explosive agent due to lightning storm (crews could safely load pipes in darkness and rain, but not during severe lightning storms)

- Supreme Court denies State of Missouri's appeal to the decision
- Stage exceeds 60.5 feet and starts overtopping the fuseplug sections in the late evening/early morning hours

May 2, 2011 (Monday)

0400: Cairo gage at 60.82
0500: Lightning storms shift to west and north allowing crews to proceed with prepping levee for activation
0600: Cairo gage at 60.97, NWS revises projected crest to 63.5 feet on 5 May
1000: Cairo gage at 61.08
1030: MVD CDR advised that explosive pumping operations would be completed in 12 hrs, at 2230 hours; MVD CDR requests plan to complete work in 8 hrs
1050: Governors, congressional members, and Chief notified of delay

- During mixing and transferring of explosive components, it is found that storage tanks containing the components cannot be completely emptied w/ equipment on site; this reduces the amount of mixture that can be generated so amount of mixture available is insufficient to fill fuseplug pipes at all 3crevasse sites. Plan developed to reduce explosive needed in middle crevasse & maintain crevasse large enough for needed stage reduction, shortening prep time needed for activation.

1515: Chief, MVM Project Management Branch directs teams to run equipment at higher rate to reduce fill time from 60 to 20 minutes for each 1,000 ft pipe section; MVD CDR presented with accelerated plan (Running the mix pump units at about 3 times the recommended rate may have affected detonation efficiency)
1630: MVD CDR officially notifies congressional members and Governors, including MO Gov Jay Nixon, that he would operate the Floodway between 2100 and 2400 hrs
1900: Cairo gage at 61.55; pumping operation complete; ERDC commences with 3-hour process to charge the lines and establish a blasting site
2030: MVM CDR informs MVD CDR the Floodway will be operational in 45 minutes
2100: Cairo gage at 61.67
2125: MVM CDR informed that Floodway is ready to operate; requests permission to operate the Floodway; MVD CDR approves the operation and proceeds to the blasting site
2200: Cairo gage at 61.72; BPNM Floodway is operated, opening the upper crevasse site with explosive material
2300: Cairo gage at 61.29
2400: Cairo gage at 61.13

Birds Point-New Madrid Floodway

May 3, 2011 (Tuesday)
0300: Cairo gage at 60.81 **0600:** Cairo gage at 60.62 **1100:** MRC briefed on status of remaining Floodway crevasse preparation. Lower crevasse is ready to operate, but there is no remaining explosive agent to fully prepare the middle crevasse. MVD CDR directs the team to procure additional explosives to open the middle crevasse. **1240:** Lower Floodway crevasse site is opened
May 4, 2011 (Wednesday)
0600: Cairo gage at 59.8
May 5, 2011 (Thursday)
0700: Cairo gage at 59.65 (May 2 NWS forecast projected the river to crest at 63.5 feet on Cairo gage on May 5) **1435:** Middle Floodway crevasse site is opened using alternative explosive agent

2. Muddy Bayou Control Structure

a. Key Decision. Whether to deviate from the Muddy Bayou Water Control Plan to help protect the Buck Chute Mainline Levee

b. Background. The mainline levee at Buck Chute is located near Eagle Lake, Mississippi 15 miles northwest of Vicksburg. This levee is part of a sub-system that protects over 1,400 square miles in the lower Mississippi River Delta from flooding. The Buck Chute levee is a chronic problem area with underseepage and sand boils commonly forming at low flood stages. Relief wells were installed to address the problems in 1999 and 2007, but new problems areas developed upriver from the improvements in 2010. Several massive sinkholes (10 to 15 feet wide and 6 to 8 feet deep) detected at the toe of the levee were caused by prior sand boil activity. The sand boils appeared at a fairly low stage (less than 1 foot above bank full) which meant that this levee issue was significant. Repairs to this levee section including a 1500 x 200-foot seepage berm and 25 relief wells were being designed, but construction was not anticipated to begin until May 2011. Temporary measures were put in place in March 2011 to address an earlier flood pulse, but these were not sufficient for the higher forecasted flood stages. When significant flooding was forecast for the Mississippi River in April 2011 the levee at Buck Chute was considered by MVK to be the weakest link in the MR&T system. A deviation from the Muddy Bayou Water Control Plan was examined as part of the emergency measures being put in place to keep the Buck Chute Mainstem Levee from failing during the 2011 Flood.

c. Operating Plan. The Muddy Bayou Water Control Structure and Operating Plan were developed as a fish and wildlife mitigation feature for the Yazoo Basin Project to prevent agricultural runoff from Steele Bayou from entering Eagle Lake. During dry periods the control structure also prevented lake water from draining into Steele Bayou. The operating plan allows for flooding of Eagle Lake to an elevation of 76.9 feet NGVD29 during 1 January – 15 June to support fish and wildlife. The need to raise the water above this level in Eagle Lake to protect the Buck Chute Levee represented a change in operation of the control structure and would require a deviation from the Muddy Bayou Water Control Plan.

d. Primary Issue at Hand. Deviating from the water control plan to raise the level of Eagle Lake would reduce the risk of levee failure at Buck Chute, but it would also potentially impact 800 residents and their property along Eagle Lake. Not deviating from the plan would result in much higher head differential between the wet and dry sides of the degraded Buck Chute mainline levee and high risk of levee failure, potentially inundating 1,450 square miles and impacting up to 3,000 homes.

e. The Operational Decision. Approval to deviate from the Muddy Bayou Operating Plan was given by the MVD Commander on 28 April 2011 and resulted in successful passage of the 2011 Flood waters through this part of the MR&T System. Many situational factors and inputs were considered in making this key operational decision. Some of the most prominent include: actual and forecasted flood crests at Vicksburg, MS; the poor condition of the Buck Chute Mainline Levee and impacts of levee failure; potential emergency measures to reduce the risk of failure of the Buck Chute Levee and; and the Muddy Bayou Operating Plan and possible impacts of deviating from the plan.

f. Play-by-Play Leading up to Key Decision. The following detailed information lays out how MVD and MVK made the key operational decision to deviate from the Muddy Bayou Water Control Plan.

Muddy Bayou Control Structure

April 22, 2011 (Friday)
• MVK staff participates in Lower-Ohio Mississippi River coordination teleconference which includes NWS forecasters and the Corps water control managers. Meeting participants are informed that the NWS forecast calls for 59 feet on Greenville gage on May 11 and 53.5 feet on Vicksburg gage on May 13. A gage reading of 53.5 feet would equate to the second highest stage ever recorded on the gage and represents a massive flood. • MVK staff move forward with preparation for the flood, including work on the mainline levee at Buck Chute, considered the weakest link in the MR&T system. • MVK team of geotechnical, hydraulics, operations, and project management staff begin analyzing various options to address the Buck Chute levee problems • MVK staff deploy to the site to further assess the conditions, available resources, and move forward procuring a workforce and equipment
April 23, 2011 (Saturday)
• District equipment is on site moving forward with constructing a large clay berm surrounding the 2 acre problem area along the Buck Chute levee
April 25, 2011 (Monday)
• Vicksburg gage at 39.2 feet • MVK multi-discipline team assess the situation at the Buck Chute are not confident the berm alone will be sufficient to address the levee sand boil and underseepage issues that could result in the levee being undermined during the forecasted flood. Geotechnical engineers on the team advise creating a similar levee head differential that was seen during the 2008 flood where the levee did not fail • MVK develops a plan to create the needed head differential using both the sand/clay berm and covering this with a blanket of water to add extra weight and pressure to the landside of the levee. Based on forecasted crest of 53.5 feet, they will need to raise the berm and water to 87 feet (10 feet higher than the existing ground). • MVK determines that placement of the water behind the levee will require a deviation from the water control plan for the Muddy Bayou Control Structure to raise the elevation of Eagle Lake. • MVK begins coordinating the deviation request with MVD, USFWS, MS and LA Depts. of Wildlife, the Warren County Board of Supervisors, the Madison Parish President, and state and local entities
April 27, 2011 (Wednesday)
• MVK formally sends the deviation request to MVD CDR who would have to approve it
April 28, 2011 (Thursday)
• Vicksburg gage at 41 feet • MVK CDR and staff meet with MVD CDR to discuss the deviation request: The mainstem levee at Buck Chute is considered the weakest link in the MR&T system. Based on Buck Chute Levee's current degraded condition, MVK staff does not think it can withstand the forecasted flood crest pressure w/out added hydraulic counter pressure. The elevated water levels needed to achieve the counter pressure could be provided by deviating from the Muddy Bayou Water Control Plan. The deviation could impact up to 800 residents around Eagle Lake, however, not deviating would very likely result in the Buck Chute Levee failing and inundation of approx 3,000 homes and 1,450 square miles. MVK asserted that the deviation is absolutely necessary because there are no other available options. • MVD CDR concurs with the MVK CDR and approves the deviation request
April 29, 2011 (Friday)
• MVK CDR MVK CDR and the Levee Board Chief Engineer, conduct a public meeting in Eagle Lake to explain the need and consequences of raising lake levels. The approximate 500 attendees are more concerned with potential Buck Chute levee failure than raising lake levels. MVK CDR reports that the Eagle Lake raise would reduce risk of levee failure, but not eliminate it. He urges meeting attendees to take appropriate steps to protect their lives and property.

Muddy Bayou Control Structure

April 30, 2011 (Saturday)

- Vicksburg gage exceeds flood stage at 43 feet
- MVK opens gates at the Muddy Bayou Control Structure and begins raising Eagle Lake to the elevation needed to protect the Buck Chute levee. The water levels will rise to 80 feet by May 2 and 1.5 feet higher per day until it reaches the needed 87 feet

May 4, 2011 (Wednesday)

- Eagle Lake residents told to evacuate by Sheriff Martin Pace

May 7, 2011 (Saturday)

- Construction of the sand/clay berm is complete at Buck Chute

May 10, 2011 (Tuesday)

- Eagle Lake level is raised to 89.8 feet to maintain the needed levee head differential with the higher forecasted crest. The original deviation request allows this because it was worded to be flexible and permit a raise up to 90 feet if the forecasted crest changed.

May 19, 2011 (Thursday)

- Vicksburg gage crests at 57.1 feet and Buck Chute mainstem levee passes flood waters without failure

3. Yazoo Backwater Levee

a. Key Decision. Whether to perform flood fight measures at the Yazoo Backwater Levee

b. Background. The Yazoo Backwater Levee is located ten miles north of Vicksburg, Mississippi and extends 28 miles from the Mississippi River mainline levee along the west bank of the Yazoo River to Yazoo City. It is one of several backwater levees in the MR&T System that are designed to slowly overtop and take pressure off the system during extremely high flood stages (approaching PDF elevations) on the Mississippi River. Up to this stage the Yazoo Backwater Levee protects 1,900 square miles of land within the Yazoo Basin. Prior to construction of this backwater levee, the most recent flood to significantly affect this area occurred in 1973 and resulted in over 1,000 square miles of the Yazoo Basin being inundated. The 1941 Flood Control Act authorized the Yazoo Backwater Levee to be built to a height equivalent to 56.5 feet on the Vicksburg gage, as long as the levee did not push river levels to within five feet of the top of mainline MR&T levees. Construction of this levee height was completed in 1978 and is what exists today. Subsequent authorization has allowed for an additional six feet of height on mainline levees and the Yazoo Backwater Levee, but the backwater levee has not been raised yet due to additional work needing to be done on mainline levees first.

c. Operating Plan. Backwater levee systems are meant to take pressure off the MR&T System mainline levees by overtopping during extreme floods. The Yazoo Backwater Levee was designed to overtop when the Vicksburg gage reached a stage of 56.2 to 56.6 feet. Further analysis by the MVK refined this estimate to 56.3 feet using updated data collected during the 2008 Mississippi River Flood.

d. Primary Issue at Hand. Based on the high forecasted flood stages in early May 2011, it was determined that the Yazoo Backwater Levee could be overtopped by as much as a foot of water for up to 10 days, which put the levee at high risk of failure. Full levee failure would result in much more significant life safety issues and damages in the backwater area than a slow overtopping event. It was estimated that if the levee overtopped without failing approximately 450 square miles would be inundated. If the levee failed, the area inundated would increase to approximately 1,900 square miles and impact more than 3,000 people. Flood fighting on the Yazoo Backwater Levee would reduce the risk of full levee failure at this location, but doing this may also increase risk to mainline MR&T levees by raising the Mississippi River flood stage. Also, there was question about the type and extent of flood fighting the Corps was allowed to do under current authorization.

e. The Operational Decision. Approval to perform flood fight measures along a four-mile stretch of the Yazoo Backwater Levee (forecasted to overtop) was given by the MVD Commander on 4 May 2011. The approved flood fight measures were fully completed by 11 May and included filling deficient low spots to authorized levels and armoring the landside of the levee with polyethylene plastic sheeting to reduce the risk of erosion and potential levee failure. Many inputs and situational factors were considered in making this key operational decision. The most prominent include: examination of authorized flood fight activities for this backwater levee; actual and forecasted flood crests at Vicksburg, MS; potential impacts of full levee failure compared to levee overtopping without failure; 2008 flood data and observations; and additional flood fight measure effects on mainstem flood levels.

f. Play-by-Play Leading up to Key Decision. The following detailed information lays out how MVD and MVK made the key operational decision to perform flood fight measures at the Yazoo Backwater Levee.

Yazoo Backwater Levee

May 2, 2011 (Monday)

- NWS forecasts a flood crest of 57.5 feet on the Vicksburg gage on 20 May
- MVK water control engineers realized that the Yazoo Backwater Levee would overtop by more than 1 ft based on the forecast (overtop begins at 56.3 on the Vicksburg gage)
- MVK contacts Mississippi Levee Board Office to inform them that they expect the 28-mile backwater levee to overtop by more than a foot for at least 10 days
- The Mississippi Levee Board was not greatly concerned with the additional water the overtopping would bring, but they were concerned with the integrity of the levee under duration and magnitude of the forecasted overtopping conditions and the significant flooding that could result from full levee failure

May 3, 2011 (Tuesday)

- MVK conducts further analysis of data collected during the 2008 flood and determines that only a 4-mile stretch of the backwater levee (from mainline levee to Steele Bayou Control Structure) would overtop based on the current forecasted crest
- MVK team examines impacts of temporarily raising the backwater levee

May 4, 2011 (Wednesday)

- During the morning Commanders briefing, MVK CDR informs MVD CDR that Mississippi Gov. Haley Barbour was assembling a task force to assist in the flood fight. The Mississippi Levee Board and state were prepared to formally ask the Corps to raise or armor the four-mile stretch of levee at risk of overtopping.
- MVD CDR states further information is needed on the potential impacts of flood fighting on the MR&T system
- Further discussion takes place on the Yazoo Backwater Levee at a meeting with the MVD CDR, MRC, and MVK CDR after the morning briefing
  - Subsequent authorizations allow for the levee to be raised by almost 6 feet, but that was most likely contingent upon work not finished yet on the mainline levees
  - Sections of the backwater levee were currently deficient, being as much as one foot lower than currently authorized levels (based on the 56.3 stage at Vicksburg). These areas needed to be raised to prevent premature overtopping
  - MVD CDR asks MVK CDR to prepare and present a decision briefing later in the evening
  - MVD CDR reminds meeting participants that the MR&T must be operated as a system and the integrity of the mainline levee is crucial
- MVK engineers determine that the Corps does not have authority to perform flood fight measures along the backwater levee that raise mainstem flood waters
- Flood fighting along the backwater levee was beyond the MS Levee Board's current resources due to current flood prep work by the Board's crews across the system
- Mississippi Levee Board sends official request to MVK CDR asking MVK to assume leadership of any flood fight on Yazoo Backwater Levee west of Hwy 61
- MVK staff (Simrall and Parish) conduct public meetings in Rolling Fork and Yazoo City to keep public informed of developments, answer questions, and eliminate rumors
  - The public was worried because of the forecast being 6 ft higher than 1973 flood and not understanding the capability of the current backwater levee to reduce impacts
  - 1,500 people attend Rolling Fork meeting and 700 attend Yazoo City meeting
  - Rumors include idea that the Corps would blow the levee similar to Birds Point
  - Staff discuss potential impacts of overtopping, full levee failure, the Corps preparation for the flood, and gave instructions on preparations for evacuation

2100: MVK CDR briefs MVD CDR and MRC members on the Yazoo Backwater area. MVK CDR provides background information on the backwater area and how its operation relates to the Vicksburg gage. He then shows two inundation maps comparing the extent and impacts of flooding. The first map shows the 450 square miles being impacted with a levee overtopping event based on the current forecasted crest of 57.5. The second map shows the 1,900 square miles inundated due to full levee failure during the current crest. MVK CDR further explained that over 3,000 people would be impacted by a levee failure.

- MVK CDR finishes his briefing with a request to raise deficient low spots to elevation 107 (equates to the authorized level of 56.5 feet on Vicksburg gage) and armor the landside of the backwater levee along the four-mile overtopping stretch to reduce the risk of erosion and levee failure.
- MRC members concurred with the Col's request and MVD CDR approves the recommendation

Yazoo Backwater Levee

May 5, 2011 (Thursday)
• MVK proceeds with work to fill deficient low spots and armor Yazoo Backwater Levee with landfill liner (40 mm thick and more durable than standard poly sheeting)
May 7, 2011 (Saturday)
• Liner delivered to location and installation begins
May 11, 2011 (Wednesday)
• Vicksburg gage has surpassed 1973 and 2008 levels and is approaching 54 feet • Liner installation complete along with all other levee preparation activities
May 19, 2011 (Thursday)
• Vicksburg gage crests at 57.1 feet • Flood crest comes within inches of the levee crown, but does not overtop the Yazoo Backwater Levee

4. Morganza Floodway

a. Key Decision. Operation of the Morganza Floodway in conjunction with conditions at Bonnet Carre spillway and Old River control structure

b. Background. The Morganza Floodway is located in central Louisiana near RM 280 on the western bank of the Mississippi River. The Floodway begins at the Mississippi River, extends southward to the East Atchafalaya River levee, eventually joining the Atchafalaya River Basin Floodway near Krotz Springs, Louisiana. The purpose of the Floodway in conjunction with the Atchafalaya Basin Floodway is to operate during extreme floods to carry flood water from the Mississippi River to the Gulf of Mexico via the lower Atchafalaya River and the Wax Lake Outlet. The structure is designed to pass up to 600,000 cfs of water to the Gulf of Mexico, alleviating stress for mainline levees downstream along the Mississippi River. Prior to 2011, the Floodway had been operated only once before during severe flooding in 1973 and it passed approximately 170,000 to 180,000 cfs at its peak operation.

c. Operating Plan. Based on the Morganza Floodway design and Water Control Plan, the Floodway is to be operated when the flow of the Mississippi River at Red River Landing, Louisiana (located 20 miles north of Morganza) reaches 1,500,000 cfs and is rising.

d. Primary Issue at Hand. Up to 300,000 cfs of water would need to be diverted through the Morganza Floodway based on the water control plan and forecasted Mississippi River flow of 1,800,000 at Red River Landing. The forecasted flow conditions on the Atchafalaya River combined with operating the Morganza Floodway could impact nearly 2,500 people and 2,000 homes in the Floodway and up to 22,500 people and 11,000 homes in backwater areas. Not operating the Floodway could result in other mainline levees overtopping or failing with much more significant damages and potential loss of life. If operated, the timing and magnitude of Floodway operation also required careful examination to balance the needed reduction in flood flows on the Mississippi River with minimizing the damages in the Floodway and on the control structure itself (which could be damaged if operated too quickly). Scenarios comparing the potential impacts of operating the Floodway against the impacts to the MR&T System below Morganza needed to be examined. Finally, the timing of Floodway activation was called into question as the flood flow neared the activation point of 1,500,000 cfs at Red River Landing. It was found that the stage at the Morganza Floodway structure was higher than anticipated given the current flow conditions at Red River Landing which could require earlier than anticipated Floodway activation. As the flood flow neared the activation point the lack of remaining freeboard and initial overtopping of the structure could make the gate opening more difficult.

e. The Operational Decision. Operation of the Morganza Floodway was initiated at 1500 hours on 14 May and resulted in successful passage of 2011 Flood waters through this part of the MR&T System with a peak flow of 186,000 cfs through the floodway. Conditions at the Old River Control Complex played a major part in activating the floodway along with several other important situational factors and inputs. The most prominent include: the Floodway water control plan; actual and forecasted discharges at Red River Landing, Louisiana; stages and remaining freeboard at the Morganza Spillway structure; potential impacts of activating the structure on the Floodway; potential impacts of not activating the structure on MR&T mainline levees and the areas they protect; and potential impacts based on how quickly the Floodway is operated.

f. Play-by-Play Leading up to Key Decision. The following detailed information lays out how MVD and MVN made the key operational decision to operate the Morganza Floodway.

Morganza Floodway

March 11, 2011

- MVN mailed annual written notices to all interests and landowners within the Morganza Floodway reminding them of the possibility of the floodway operation.

April 28, 2011 (Thursday)

- MVN sends flood notification letters to Morganza Floodway landowners advising them of the possibility of needed evacuation

May 2, 2011 (Monday)

- NWS forecasts the flood flow at Red River Landing, Louisiana will reach 1,800,000 cfs in early May

May 3, 2011 (Tuesday)

- MVN CDR informs MVD CDR and the MRC that the NWS and MVN water control managers anticipate the Mississippi River will quickly surpass the activation point (1.5 million cfs at Red River Landing) to operate the Morganza Floodway by as early as 11 May
- MVN CDR sends memorandum to MVD CDR and MRC requesting permission to open the Bonnet Carré Spillway
- MVD CDR acknowledges receipt of the Bonnet Carré Spillway request and that the MRC had it under advisement
- MVD CDR requests that MVN CDR provide a briefing on the Morganza Floodway

May 4, 2011 (Wednesday)

- MVN CDR provides briefing detailing the layout, trigger points, and operation of the Floodway. The CDR lays out the timeline for Floodway activation based on current forecast, including activating the Floodway at 1,300,000 cfs (rather than 1,500,000) to allow for a slower, less damaging activation process (environmentally and structurally)
- Initial Floodway inundation modeling was performed

May 5, 2011 (Thursday)

- MRC votes unanimously to give MVN CDR authority to open Bonnet Carré Spillway in accordance with the approved water control manual
- MVN staff meet with LA Gov., parish presidents, levee boards, and other stakeholders to discuss Morganza Floodway operation and land owner preparation and evacuation

May 6, 2011 (Friday)

- MVN CDR sends memorandum to MVD CDR and MRC requesting approval to operate the Morganza Floodway
- MVN informs MVD CDR and MRC of mainline levee concerns between Baton Rouge and Bonnet Carré if Floodway is not operated during current forecasted flood. This included significant underseepage at Duncan Point, and the Morganza structure itself could be overtopped and the resulting scour could jeopardize its stability
- MVN CDR provides second decision briefing on Morganza Floodway and an updated timeline of operation. MVN CDR cites 1973 PFR recommendations to support need to slowly operate the Floodway to reduce environmental and structural impacts (e.g., extensive scour damage during 1973 operation)
- Updated inundation modeling and maps show a potential impact to nearly 2,500 people and 2,000 homes in the Floodway and up to 22,500 people and 11,000 homes in backwater areas
- MVD CDR contacts Corps HQ to inform them of potential impacts
- Corps HQ requests assessment of alternate scenarios comparing potential impacts of operating the Floodway vs impacts to MR&T System below Morganza if it is not operated
- MVD CDR instructs the Chief of MVD's Watershed Division to work with MVN to develop assess various scenarios. Three scenarios are examined: (1) adhering to the approved water control plan and diverting 300,000 cfs through Morganza; (2) not operating the Floodway and attempting to pass 1,800,000 cfs through the mainline MR&T with increased flood fight measures; and (3) avoid operating the Morganza Floodway and pass an additional 300,000 cfs through the ORCC.

Morganza Floodway

May 7, 2011 (Saturday)

0700: Flow at Red River Landing is 1,180,000 cfs

May 8, 2011 (Sunday)

0700: Flow at Red River Landing is 1,240,000 cfs

May 9, 2011 (Monday)

0700: Flow at Red River Landing is 1,320,000 cfs

- Bonnet Carré Spillway is opened
- MVN CDR conducts briefing with MVD CDR and MRC and presents the 3scenarios related to the Morganza Floodway operation. The CDR discusses the pros and cons of the scenarios and emphasizes that the scenario of operating the Morganza Floodway poses the least risk to the MR&T system. He also communicates recent issues brought to the attention of MVN regarding the potential closing of the system to commercial navigation and shutdown of a nuclear power plant if the Morganza Floodway is not operated
- MVD CDR concurs with MVN CDR 's recommendation to operate the Morganza Floodway and confirms that he will operate the Floodway according to the water control plan (when 1,5000,000 cfs is reached at Red River Landing)

May 10, 2011 (Tuesday)

0700: Flow at Red River Landing is 1,360,000 cfs

- MVN staff identify that the discharge trigger of 1,500,000 cfs at Red River Landing is not correlating to the proper stage at the Morganza Floodway structure (1.5 million cfs originally corresponded to no more than 56 feet at the spillway, leaving 4 feet of freeboard). Previous floods had shown a progressive deterioration of discharge capacity in this reach of the system. The result was higher stages were now being observed at the Morganza Floodway structure during lower flood discharges at the Red River Landing. This put the Morganza Floodway structure in danger of overtopping and being extremely difficult to open before the activation discharge of 1,500,000 cfs was reached. Overtopping also threatened the integrity of the structure itself.

May 11, 2011 (Wednesday)

0700: Flow at Red River Landing is 1,394,000 cfs

- NWS adjusts forecast for Red River Landing from 1,800,000 cfs to 1,626,000 cfs in mid May
- Stage is 57 feet at the Morganza Floodway structure (1 foot higher than assumed design stage for activation)
- MVN CDR informs MVD CDR that the Morganza gates are within three feet of overtopping and discusses the concerns associated with this
- MVD CDR requests MVN run the three scenarios again with the new NWS forecast
- Volunteer evacuation of the Floodway is proceeding slowly

May 12, 2011 (Thursday)

0700: Flow at Red River Landing is 1,423,000 cfs

Morganza Floodway

May 13, 2011 (Friday)

0700: Flow at Red River Landing is 1,449,000 cfs

- MVN CDR informs MVD CDR and MRC that the Bonnet Carré Spillway would reach its design capacity discharge sometime that day
- Stage is 58.6 feet at the Morganza Floodway Structure (1.5 feet from overtopping)
- MVD CDR sends official order to MVN CDR to prepare to operate the Floodway within 24 hours upon MVD CDR's order to execute and IAW with the approved operational plan
- MVN staff at Morganza Floodway structure monitors situation and gages around the clock

2200: River stages at Morganza start to increase more rapidly and would most likely overtop the floodway structure gates during the evening

- MVN instructs gate operators at Old River auxiliary structure to divert more water to keep the Morganza gates from overtopping

May 14, 2011 (Saturday)

0700: Flow at Red River Landing is 1,470,000 cfs

- Forecast for Red River Landing is 1,480,00 cfs for 14 May
- Stage is 59.4 feet at the Morganza Floodway structure (waves are spilling over the Floodway gates)
- MVD CDR and MRC arrive at Morganza Floodway structure to directly inspect conditions
- MVN CDR conducts briefing with MVD CDR and MRC at the Morganza Floodway, going over current and forecasted conditions. Although the activation stage would most likely be reached on 15 May, current and increased gate overtopping was leading to a serious problem of making the gate opening much more difficult. To address the overtopping and gate opening issue, MVN would most likely have to deviate through Old River if the Morganza Floodway was not going to be operated until 15 May.
- MVN CDR requests permission to operate the Morganza Floodway at 1500 hours on 14 May
- MRC members concurred with MVN CDR's recommendation
- MVD CDR approves MVN CDR 's request to operate the Morganza Floodway at 1500 hours due to Mississippi River flows approaching 1,500,000 cfs and rising at Red River Landing
- MVD CDR calls the Governor of Louisiana to notify him of the decision
- The governor informs him that the Floodway is clear

1500: The Morganza Floodway is operated with the first gate being opened. A second gate was opened later in the evening.

May 15, 2011 (Sunday)

0700: Flow at Red River Landing is 1,495,000 cfs

- Nine more bays opened at the Morganza Structure directing 100,000 cfs into the Morganza Floodway. Additional bays would continue to be opened daily until 18 May, when a total of 17 bays were open, resulting in a peak flow of 186,000 cfs.

SECTION V

AREAS FLOODED, FLOOD DAMAGES, AND FLOOD DAMAGES PREVENTED

A. INTRODUCTION

The Mississippi River floods in April and May 2011 were among the largest and most damaging recorded along the US waterway in the past century with flows and stages that were comparable in magnitude to the major floods of 1927 and 1993.

Large portions of the LMRV are subjected to significant loss and damage when the Mississippi River overflows its banks. During major floods, the region experiences flood damage (economic losses) to unprotected areas between the levees and backwater areas up the tributaries. These damages are associated with farmland, homes, businesses, personal property, roads, and bridges. Additionally, many people are left without shelter, utilities, and food and are inconvenienced by an interruption in daily activities and loss of income. The following section discusses flood damage impacts for the LMRV region in terms of population, number of structures impacted, agricultural acres flooded, flood damages, and flood damages prevented by the MR&T project.

The geographic extent for the MVD Post Flood Report includes the area encompassed by the maximum extent of without project flooding for the Mainline Mississippi River headwater and backwater flooding from the vicinity of Cairo, IL to the Gulf of Mexico, including the Atchafalaya River, as well as the maximum extent of without project flooding below Wappapello Dam. This maximum extent was delineated by completing a hydraulic model of the mainline Mississippi River and the area below Wappapello Dam using without - project flows and without levees to represent natural conditions. The resulting extent was used to establish a comprehensive and consistent geographic boundary on which a repeatable economic analysis could be performed. The economic analysis was performed to estimate the damages prevented by the MR&T system and its operation within the boundaries of the MVD during the 2011 Flood with the intent to:

(1) not include the Ohio River reservoirs as they are not officially part of the MR&T (recognize they have operation authority to support MR&T), these benefits are being computed by LRD and would be included in more comprehensive Greater Mississippi Basin System Performance Assessment .

(2) include Wappapello Dam in the analysis as this project was authorized by the MR&T project and experienced historical flooding in the 2011 Flood.

(3) not include the Yazoo tributary reservoirs because of the additional modeling effort and time required to capture local headwater flooding that had relatively no impacts or benefit to MR&T during this event.

The economic analyses utilized inundations generated from numerical hydraulic model output and other data to identify types and locations of properties impacted by the 2011 Flood and assess damages associated with these impacts. Three models, Hydrologic Engineering Center's River Analysis System (HEC-RAS) Program, the Flood Event Simulation Model (FESM), and Hydrologic Engineering Center's Flood Impact Analysis (HEC-FIA) Program were utilized in the evaluations. The models were used to generate predicted inundation boundaries for three scenarios to compare to the actual inundation area associated with the 2011 Flood. The actual 2011 Flood (Model Scenario 1) and the three other modeled scenarios are defined in Section V.B.

Two major categories of damages were evaluated based on the availability of flood damage information captured from the flood event. These included flood damages to urban properties, or structures and flood damages to agricultural properties, including crops. It is worth noting that flood impacts occurred to other damage categories, such as roads, bridges, infrastructure, navigation, etc., but, due to time constraints and the availability of information and feedback, these damages are not included in this evaluation. For similar reasons, a comprehensive scenario-based analysis was not done for impacts to the environment. This section later addresses the damages to the environment due to the 2011 Flood as it occurred.

B. MODEL SCENARIO ANALYSIS METHOD

The four scenarios were modeled to allow comparison of actual damage estimates (based on the existing conditions) with damages estimates based on what would have occurred if some FRM features were not present or utilized.

- **Scenario 1 (Existing) -** the existing 2011 scenario as it occurred during the 2011 Flood event (i.e., with levees and flood control reservoirs in place, including deviations to reservoirs' Operation Plans).

  HEC-RAS was used to model this scenario because most flooding is within the levees; therefore, the assumption that the majority of the flow is downstream is accurate and can be captured with a 1D model. The flooding that is not within the levees is backwater flooding at major tributaries which can be accurately modeled with tributary reaches and storage areas within the HEC-RAS program.

- **Scenario 2 (No Levees and Cutoffs) -** the scenario with no levees, but with flood control reservoirs (i.e. without levees and associated cutoffs but assuming all reservoirs are in place). Between 1932 and 1942, the Mississippi River Commission executed 15 artificial cutoffs, or newer and shorter channels in the river that cut across bends in its course, to improve the carrying capacity of the channel and lower the project flood flow line. These artificial cutoffs reduced the length of the river by nearly 170 miles.

  Because of the large amount of levees along the Mississippi River, any scenario without levees would have a large spreading type inundation that cannot be accurately modeled with HEC-RAS. This scenario was modeled using a simplified method developed and used by the MVD to analyze benefits of levees, cutoffs, and floodways (i.e., pre-MR&T conditions). This method uses stage and flow information collected in 1912; therefore this method reflects river conditions that existed before the MR&T project was constructed. While some local levees did exist prior to the MR&T project, they were generally lower and had a smaller cross-section and would have certainly been overtopped by the 2011 Flood. By using this information, an accurate estimate can be made of the 2011 river stages if levees were not present. From the calculated stages, inundation extents and depth grids were produced by MVK's Flood Event Simulation Model. This model is a tool widely used by MVK to produce flood extents from forecasted stages. This simplified method was chosen because of its wide use within MVD and the time frame in which the method could be completed. If the schedule would have allowed for it, this scenario would have been also modeled with FLO-2D. If the modeling effort with FLO-2D was acceptable, the results from the simplified method could be verified and, if necessary, refined.

- **Scenario 3 (No Levees, Cutoffs, and Reservoirs) -** the scenario with no levees and no federal flood control reservoirs. A modification of the MVD simplified method was used to complete this scenario. The flows developed for a No Reservoirs scenario were utilized, which includes no Federal reservoirs on the Missouri and Ohio River basins. The same justification for using the simplified method is applicable for this scenario.

- **Scenario 4 (No Deviations/Directives) -** the existing 2011 scenario without deviations or directives to flood control reservoirs' Operation Plans Discharges without deviations at Corps reservoirs were calculated from the Water Control Section from each District. These discharges will replace the existing conditions discharges, and will be routed through the same HEC-RAS models created for the Existing scenario. For this scenario, an assumption was made that overtopping of levees would not occur; therefore, the assumption that the majority of the flow is downstream is accurate and can be captured with a 1D model. The only flooding not within the levees is backwater flooding at major tributaries, which can be accurately modeled with tributary reaches and storage areas within RAS.

In addition to the four scenarios above, two other scenarios, No Floodways and No Reservoirs, were initially included as part of the modeling effort to determine damages prevented by each of the system components. However, due to the short timeframe to complete modeling, these two scenarios were not analyzed for this Report. However, they may be included in the Greater Mississippi Basin Post-Flood Assessment effort being conducted by HQUSACE.

1. Model Inputs and Assumptions. The UMR contributes flow into the MR&T system that must be included in model study efforts. The upper boundary of the MR&T model on the Mississippi River is at the Chester, Illinois gage site (river mile 109.9 above the mouth of the Ohio River). The drainage area of the Mississippi River at Chester is 708,563 square miles. The six Corps offices providing Water Management within this watershed are Omaha District; Northwest Division-Omaha; Kansas City District; St. Paul District; Rock Island District; and St. Louis District. The first three offices provide Water Management for the Missouri River and tributaries while the latter three support the Mississippi River and tributaries.

2. Analysis, Data Quality, and Uncertainty. When performing the modeling for the four scenarios, it is important to note that two different modeling methods—HEC-RAS and FESM—were used. The HEC-RAS modeling produced inundation depth grids that were mainly inside levees, floodways, or natural backwater areas. Flows were readily available on all major rivers and tributaries; as a result, water surface elevations were produced at numerous points throughout the study area and used to produce the inundation depth grid. The FESM model produced inundation depth grids over very wide flood plains using a limited number of data points to produce the inundation. The methodology used to calculate the water surface elevations for the scenarios that utilized the FESM model is described in the following paragraphs. A more detailed description of the methodology used in Scenarios 2 and 3 can be found in Appendix G, *Economics*.

Due to the two different modeling approaches and extrapolation of existing flows for a scenario based on a set of curves, some uncertainty exists in the modeling results; however, the documented and scientific approach used to calculate the water surface elevations for the various scenarios does produce output that can be used to compare damages and damages prevented.

3. Modeling Environment. The hydraulic modeling of the scenarios was completed using either HEC-RAS, a one-dimensional numerical model, or FESM. HEC-RAS is a very common numerical model applied widely across the Corps. However, FESM is a flood inundation model designed to replace the FEAT Model used by the Corps. The required inputs to the model are the topography in which the simulation will take place in the form of a georeferenced DEM, the path information of river channels, optional path information of sub channels connecting to the main simulation channels, and water elevation information for known points along the simulation channels. FESM differs from most flood inundation models in that it does not considerer either flow or friction, and as a result does not need information about these conditions. Another key difference is that FESM does not directly implement either the Naiver Stocks equations, the de Saint Venant equations (Shallow Water equations), or any obvious approximation, of these equations (any attempt to create a water surface is at some level an approximation of the de Saint Venant equations). Water elevations in channel are determined by the input data and linear interpolation along channels paths if the resolution of the simulation grid is smaller than the spacing between known water elevation points. Lateral propagation of water elevation is done by selecting grid locations adjacent to the expanding flood surface, and determining which adjacent locations are potential sources of inundation. The resulting water level and a grid location depend on the water levels of such sources modified by slope rules.

4. Flood Damages Analysis. The HEC-FIA model is the tool used in this investigation to evaluate flood damages. The HEC-FIA model provides the capability to estimate the impacts associated with flood events and the benefits attributed to flood risk reduction projects. The HEC-FIA is designed to assess disaster impacts after a flood using geo-referenced data grids with inundation, terrain, agricultural, and structural data. The HEC-FIA estimates the area inundated, number of structures inundated, structure damage, agricultural flood damage, and project benefits. The HEC-FIA also has the functionality to estimate life loss during a flooding event; however, life loss will not be addressed in this report.

In FIA, the structure inventory used to calculate structure damages and project benefits can be generated from a HAZUS database, a shapefile, or can be manually entered from an existing source. HAZUS, the chosen source of structure inventories for this report, is a collection of models and databases, including an estimation of the general housing stock, developed by FEMA for estimating the impacts from natural disasters. Crop coverage used to estimate agricultural damages can be generated from the National Agricultural Statistics Service Cropland Data Layer (NASS CDL), a shapefile, or the HAZUS. The NASS CDL, the source of crop coverage for this report, is a geospatial crop-specific digital data layer used in GIS applications provided by the National Agricultural Statistics Service of the United States Department of Agriculture.

C. MODEL RESULTS

Figures V-1 through V-4 illustrate the inundation areas associated with each of the hydraulic numerical modeling scenarios described above. Additional details are provided in Appendix G, *Economics.*

Based on the model outputs alone, it is clear that the MR&T System prevents major damages over a widespread area. Furthermore, when coupling the without levees scenario along with no reservoirs, as expected, even more inundation and subsequently damages would be produced. The 'reservoir without deviations' scenario showed some increase in stages in the upper portion of the MR&T system, but those effects diminish as the floodwave progresses downstream.

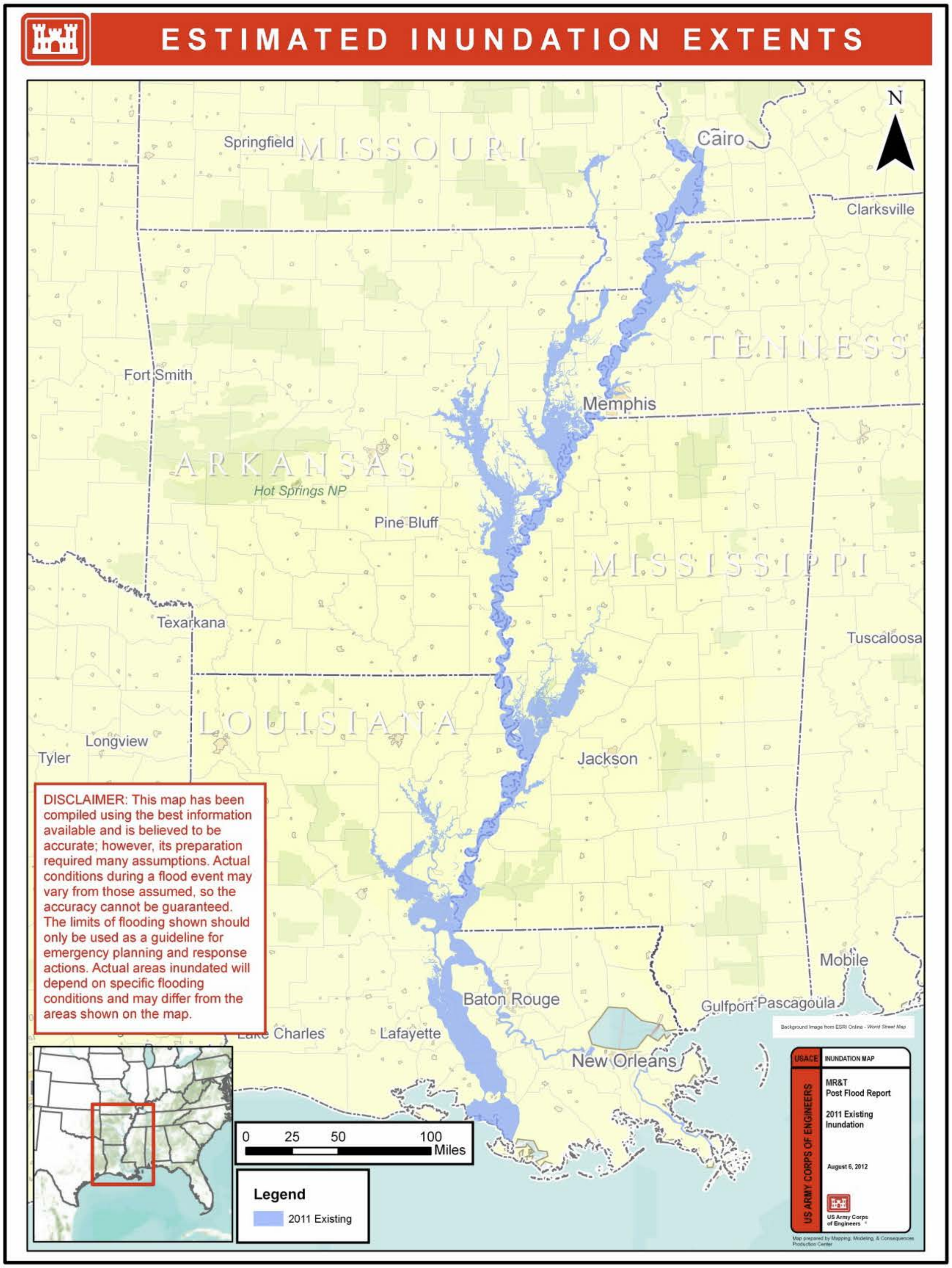


Figure V-1. Scenario 1: 2011 Existing Conditions

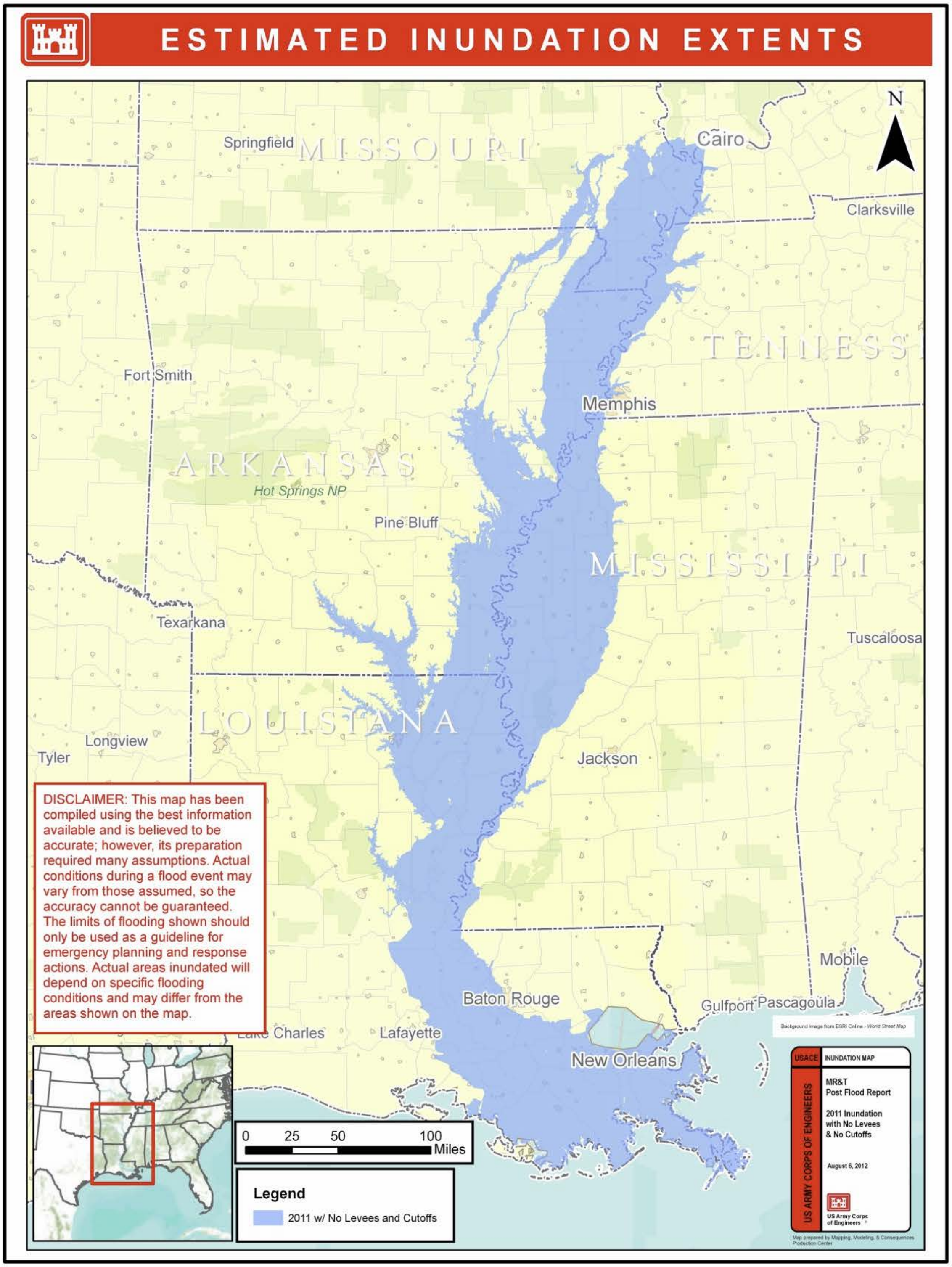


Figure V-2. Scenario 2: 2011 Without Levees and Cutoffs

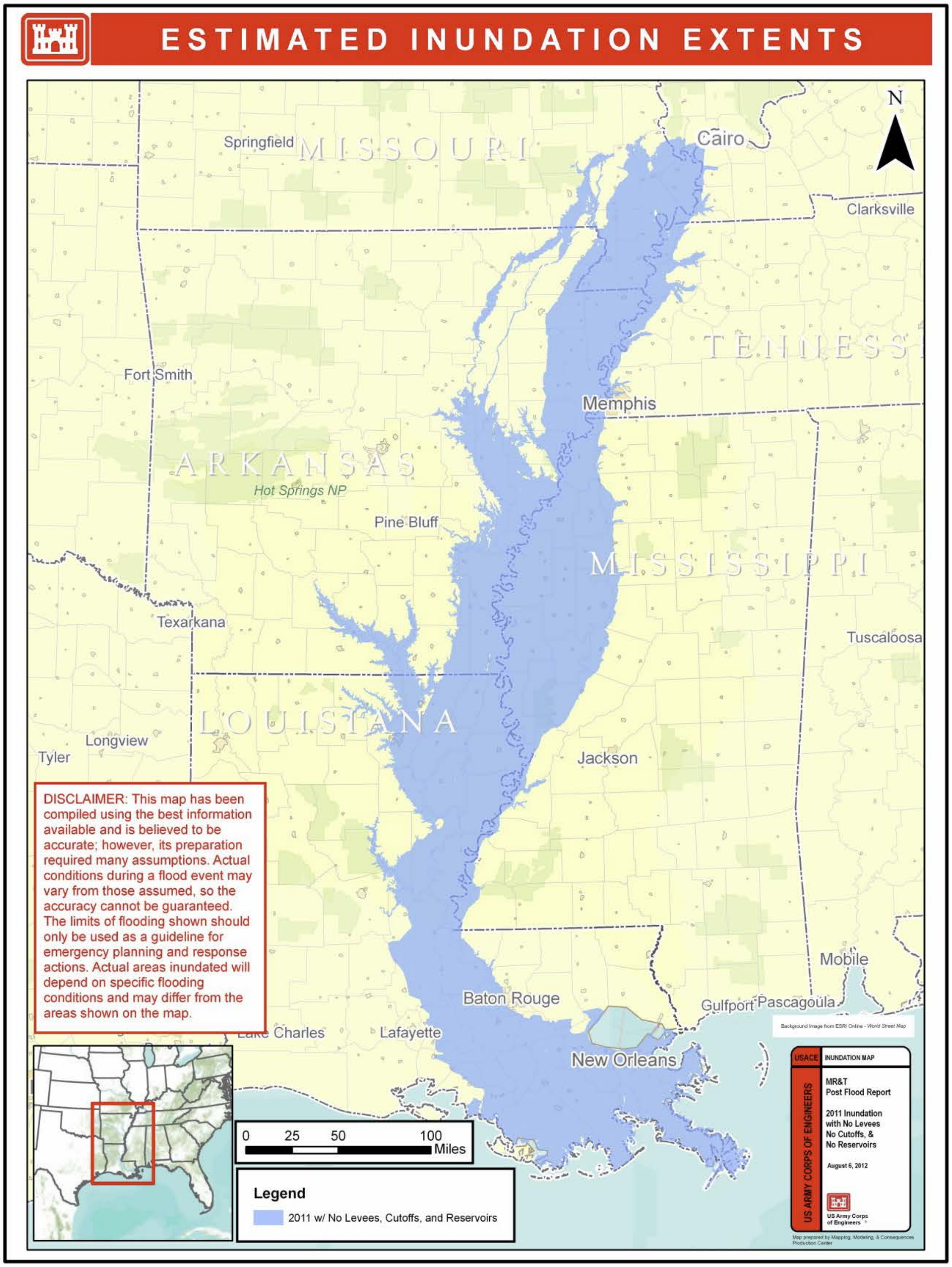


Figure V-3. Scenario 3: 2011 Without Levees, Cutoffs, and Reservoirs

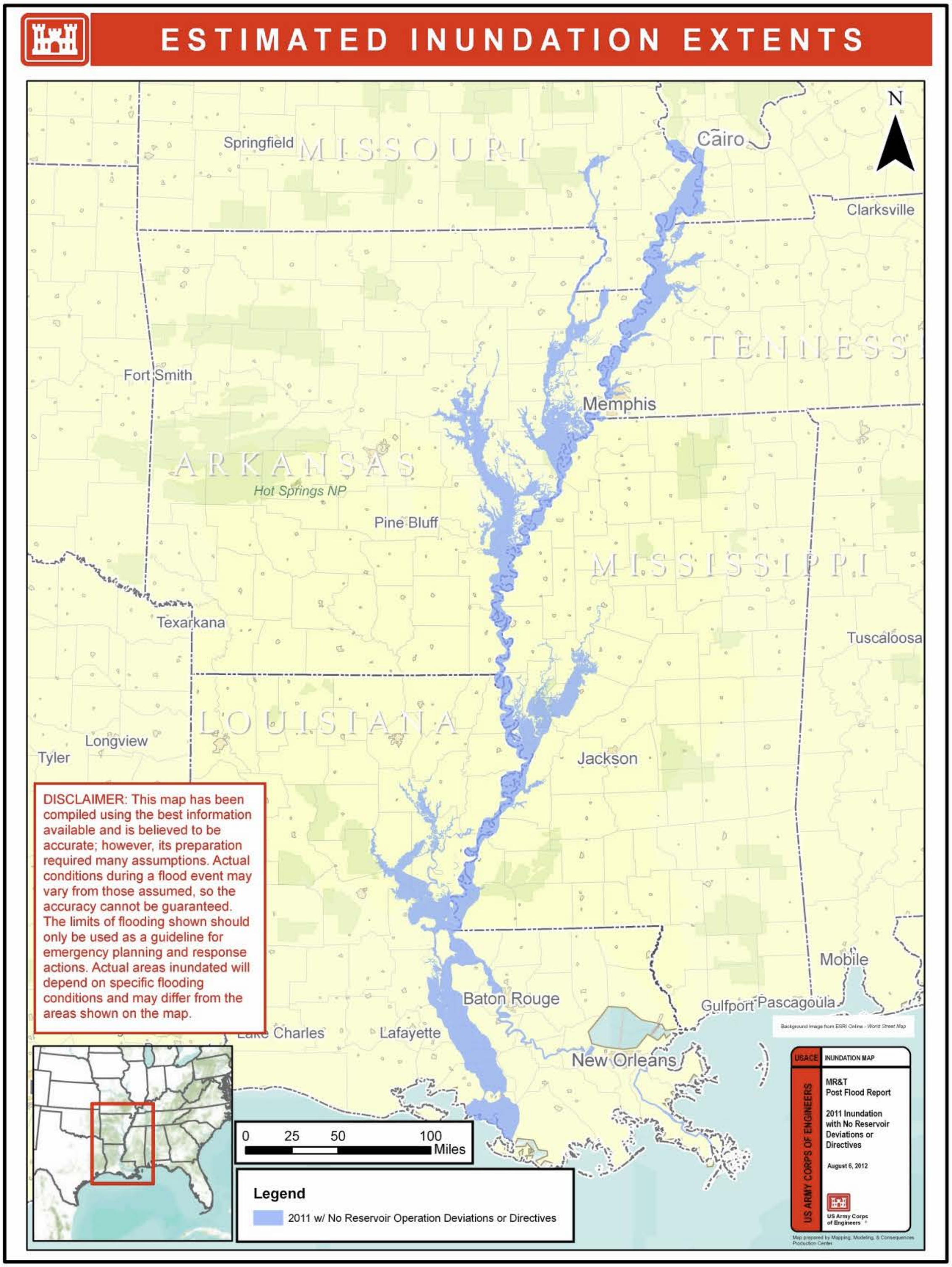


Figure V-4. Scenario 4: 2011 Existing Conditions Without Reservoir Deviations

D. AREAS INUNDATED

Flood damage impacts from the 2011 Flood were determined to impact 119 counties in portions of seven states along the lower Mississippi River—Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee. These included areas in five US Army Corps of Engineer Districts in the lower MVD—SWL, MVM, MVN, MVS and MVK. Two other districts had potential impacts, LRN and LRL. Population estimates for the 119 counties in these states totaled approximately 6.3 million in 2010, according to the US Census Bureau statistics. Based on results of HEC-FIA, 43,358 people were impacted by the 2011 Flood was. HEC-FIA results account for the exact delineated boundary of the flood, whereas Census estimates account for the entire land area of each impacted county. Census data also includes metropolitan areas which are typically protected from catastrophic flooding from the Mississippi River.

Population impacts by Corps District are presented in table V-1 for the four hydrologic scenarios. Without the MR&T Project in place (i.e., Scenario 3), an estimated 3.6 million people (3,638,005) would be impacted by the 2011 Flood event. This compares to the 43,358 people impacted during 2011 Flood event (Scenario 1). In other words, approximately 3,594,647 people were saved from flood impacts with the MR&T Project in place. Without the MR&T Project in place (i.e., Scenario 3), MVN would comprise about 72 percent of the population impacted, followed by MVK with 19 percent and MVM, 9 percent.

Table V-1. Population Impacted by Scenario and District

District	Scenario 1	Scenario 2	Scenario 3	Scenario 4
SWL	79	3,636	4,041	79
MVM	19,348	312,410	346,253	19,348
MVN	18,281	2,191,303	2,591,972	18,281
MVS	0	0	0	0
MVK	5,650	618,741	695,739	5,650
Total Area	**43,358**	**3,126,091**	**3,638,005**	**43,358**

Source: HEC-FIA output

E. FLOOD DAMAGES

1. Economic Damages. Surveys conducted during and after the 2011 Flood provided a fair insight into the types and number of properties impacted. Discussed below and in greater detail in the Economic Appendix, the two largest categories of flood damage occurred to urban structural and agricultural properties.

a. Damages to Urban Structures. The HEC-FIA software was used to generate a structure inventory for the area inundated downstream of the project during failure and non-failure flood events. US Census data at the census block level and other information from the FEMA Hazard US database (HAZUS-MH) were utilized by HEC-FIA to create the structure inventory. The structures in each census block were evenly distributed over the urbanized area within the block. The urbanized areas were extracted from the 2001 National Land Cover dataset. Structure elevations were based on an elevation grid from the USGS with a ten meter grid size. The inventory created by HEC-FIA was compared with aerial imagery and is considered to be representative of the study area. HAZUS-MH data contains numbers of structures by occupancy type. Some structure characteristics and values are based on regional averages and other assumptions that cause uncertainties in input variables of the damage estimation process.

HEC-FIA was also used for this study in the estimation of damages to property. In the computation of property damages, HEC-FIA assigns each structure a structure point or HAZUS node, a ground elevation based on its location on a digital terrain model. Flooding is computed from depth grids for each failure mode or flood event. Vehicle damages were also calculated using the HAZUS dataset. HAZUS provides estimated day and night vehicle counts and values for both new and used light trucks, heavy trucks, and cars. As with the structure inventory, this data is provided for every census block. The vehicle counts are totaled for every vehicle type and evenly distributed by the HEC-FIA program between every structure in a census block. Estimates of the number of inundated structures, the degree of inundation, and the associated dollar damages, provide a profile of the system-wide impacts associated with a given scenario. While the aggregate system-wide estimates are constructed from estimates at the level of the individual structure, definitive attribution of a specific result to an individual structure in the form of inundation, depth of inundation, or dollar damage is not appropriate.

A more detailed discussion on the parameters and calculation of structural damages is presented in the Economic Appendix (Appendix G, *Economics*).

b. Number of Structures Flooded. Based on HEC-FIA output, the total number of structures affected for the existing 2011 Flood event, as it occurred during the flood (i.e., Scenario 1), resulted in 21,203 structures. This included urban and rural residential, commercial, industrial, and public structures. For the same scenario, an estimated 43,358 people were impacted.

The number of structures flooded by Corps District is presented in table V-2 for the four hydrologic scenarios. Without the MR&T Project in place (i.e., Scenario 3), an estimated 1.45 million structures (1,459,234) would be impacted by the 2011 Flood event. This compares to the 21,203 structures flooded during 2011 Flood event (Scenario 1). In other words, approximately 1,438,031 structures were prevented from flooding with the MR&T Project in place. The MVN contains 68 percent of the structures flooded without the MR&T Project in place (i.e., Scenario 3), followed by MVK with 19 percent and MVM with 12 percent.

c. Agricultural Damages. Agriculture flood damages were evaluated for the 2011 Flood based on the four different hydrologic scenarios, previously defined, for the five Corps Districts determined to potentially be impacted by the flood — SWL, MVM, MVN, MVS and MVK. To develop the database of agricultural acres impacted, state crop data layers were provided by the National Agriculture Statistics Service (NASS) based on the 2010 crop layer. Inundation shape files were reclassified against the land layers in ArcGIS to estimate the total acres of agriculture land impacted. Table V-3 provides the results for the reclassification for each scenario. The existing conditions (Scenario 1, existing MR&T Project as occurred during the 2011 Flood) proved to yield the least amount of land impacted, 1.23 million cleared acres compared to the other scenarios. As expected, Scenario 3 (no levees, no reservoirs) showed the largest total of land inundation (10.2 million acres) when evaluated against the other scenarios.

Table V-2. Number of Structures Flooded By Scenario and District

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	With MR&T Project (as occurred in 2011 event, minor deviations to reservoirs)	**Without MR&T Project** (no levees or cutoffs but w/ reservoirs)	**Without MR&T Project** (no levees, cutoffs or reservoirs)	**With MR&T Project** (as occurred in 2011 event, with no deviations to reservoirs)
SWL	70	3,171	3,507	70
MVM	9,747	155,682	172,130	9,747
MVN	6,799	849,826	999,238	6,799
MVS [1]	0	0	0	0
MVK	4,587	253,667	284,359	4,587
Total	**21,203**	**1,262,346**	**1,459,234**	**21,203**

Source: HEC-FIA output

[1] No site specific survey data on individual structures was available, thus it was difficult to determine damages in these areas with any degree of accuracy. Based on FEMA information, some structures did receive flood damages during the 2011 Flood event but no damage estimates were available.

Table V-3. Total Agriculture Acres Impacted by Scenario and District

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	With MR&T Project (as occurred in 2011 event, minor deviations to reservoirs)	**Without MR&T Project** (no levees or cutoffs but w/ reservoirs)	**Without MR&T Project** (no levees, cutoffs or reservoirs)	**With MR&T Project** (as occurred in 2011 event, with no deviations to reservoirs)
SWL	34,800	210,500	212,200	34,800
MVM	620,000	2,696,900	2,707,940	620,000
MVN	52,300	1,295,500	1,310,900	52,300
MVS	92,500	675,500	681,860	92,500
MVK	433,500	5,295,200	5,322,800	433,500
Total Area	**1,233,100**	**10,173,600**	**10,235,700**	**1,233,100**

Source: NASS and ArcGIS.

Values indicated are estimated areas of inundation calculated using hydraulic numerical modeling that required assumptions and simplifications.

d. Crop Data. For this study damages were calculated for the following crops: corn, winter wheat, soybeans, grain sorghum, cotton, rice, and sugarcane. These crops constitute the majority of production in the impacted area. Crop budgets used to determine production costs and potential net income from lands in production were taken from budgets prepared by Mississippi State University's Agriculture Extension Service. Crop prices were based on current market prices available in May 2012. Crop yield data was obtained from agronomy experts with Louisiana State and Mississippi State University Extension Services. Damage to farms was evaluated based on three broad categories; production losses, net returns losses, and non-crop damages. All monetary damages were indexed to 2012 dollars.

e. Crop Loss Assumptions. Due to extended duration of the flood of 2011, it was assumed that replanting following the flood was not possible. After the flood started in April, it was assumed that no production costs were expended by farmers. Detailed explanations of the processes utilized to compute agricultural damages are provided in the economic appendix section of the document.

f. Total Economic Damages. The levees along the Mississippi River protect one of the most productive agricultural areas in the world, in addition to many other developments which have occurred over the years. Total flood damage estimates are presented by District in tables V-1, V-2, and V-3 for the four hydrologic scenarios and can be found in Appendix G, *Economics*. Total flood damage estimates from the 2011 Flood, with all current operational features of the MR&T project in place (Scenario 4), totaled over $2.8 billion in urban and agricultural damages. Without a FRM system in place, total flood damages were estimated to exceed $237 billion (Scenario 3). This amounts to $234 billion in savings with the System in place. Total flood damages for Scenarios 2 and 1 were estimated at $225 billion and $2.8 billion, respectively.

Flood damages of these sizes would almost certainly be accompanied by the threat of loss of life and would devastate millions of acres of farmland, numerous communities, homes, and businesses, and disrupt associated infrastructure. The possibility of a flood of this magnitude would be catastrophic to the economy of the region and repercussions would be felt throughout the entire US economy.

- **Scenario 1 - Flood Damages.** Urban flood damages comprise 76 percent of the total flood damages for Scenario 1—the condition as it occurred during the 2011 event. The damages are distributed between in MVN, MVK and MVM (38, 21 and 37 percent, respectively).

- **Scenario 2 - Flood Damages.** With no MR&T levees or cutoffs, but with reservoirs, urban flood damages would consist of 97 percent of the total flood damages. For this scenario, the majority of the total damages would take place in MVN (74 percent), followed by MVK and MVM, with 17 and 8 percent, respectively.

- **Scenario 3 - Flood Damages.** Without the MR&T Project, urban flood damages would account for 98 percent of the total flood damages. The majority of the total damages would happen in MVN (74 percent), followed by MVK (17 percent) and MVM (8 percent).

- **Scenario 4 - Flood Damages.** For Scenario 4—with the MR&T in place, as it was designed—urban flood damages comprise 76 percent of the total flood damages. The total damages are distributed between in MVN and MVM (37 and 38 percent, respectively) with MVK comprising 21 percent.

g. Damages to the MR&T System. The MR&T System consists of levees, drainage structures, pumping plants, channel improvement features, and various other structures. These levee systems are shown in Appendix G, *Economics*. The Immediate Risk Reduction Measures include needs of the MR&T System that were defined as Classification 1 projects in accordance with the Hot Spot Project FRAGO. These projects remediate issues identified during the 2011 event that are likely to cause failure prior to a 25-year flood event. The Long Term needs of the MR&T System are defined as Classification 2 and 3 projects in accordance with the FRAGO. These projects remediate issues identified during the 2011 event that range from unlikely to likely chance of failure due to a 25-year flood event. Further information on damages to MR&T features can be found in *Section VI. C. Damage and Repair Needs* which provides a detailed explanation and results of the MR&T damage assessment conducted by Corps staff.

In addition to levee structures and their features, the Channel Improvement community has identified approximately 240 MR&T channel improvement sites that sustained damage to revetment and/or dikes during the 2011 Flood on the Mississippi and Atchafalaya Rivers, 44 of which could have an impact on system performance if not repaired. Some of the most significant include Cache-Cairo, Third District, Chute of Island 8, Merriwether-Cherokee, President's Island, and Walnut Point/Kentucky Bend. A brief discussion of the each of these can be found in Appendix G, *Economics*. Typical damage is shown in photographs V-1 through V-4.

Photograph V-1. Typical Damage to a Dike

Photograph V-2. Typical Damage to Revetment

Photograph V-3. Location of Critical Scour

Photograph V-4. Example of Overbank Scour

2. Environmental Damages. During the 2011 Mississippi River flood, large reaches of river channel and floodplain experienced high rates of soil/sediment erosion and deposition along with vegetation loss. While these are processes associated with natural river behavior, anthropogenic development has led to an intensification or spatial redistribution of the flooding impacts. For example, many of the major observed environmental impacts occurred in the three large engineered spillway or floodway areas that were activated during the flood: the BPNM Floodway, the Morganza Floodway, and the Bonnet Carré Spillway. Most damage resulted from the force of the initial flood wave as the spillway gates were opened, and the prolonged inundation of the spillway area. Further environmental effects occurred as the large volumes of river water were introduced into coastal estuary locations, which only receive large influxes of fresh water on a periodic basis.

a. Terrestrial Resources

i. Land Resources. During the flood of 2011, the increased river stage caused the rerouting of relatively high velocity flow over many channel bars, islands, and point bars. In the past, the Corps recommended a minimum 'tree screen' of 300 feet perpendicular to the channel bank to inhibit the passage of strong river currents over inundated floodplain areas during floods. Many reaches of the river lack even this screen, and field evidence suggests that such scour damage is more likely with the lack of a tree screen. For example, sites such as the Merriwether-Cherokee Revetment site in Lake County, TN and President's Island in Shelby County, TN (photographs V-5 and V-6 and figureV-5) experienced severe damage that may have been avoided if tree screens were present. Future implementation of tree screens or their beneficial functions should be considered with regard to local bank heights, overbank flow patterns, soil types, and vegetation types to enhance their resiliency and effectiveness. The Thompson Bend Riparian Corridor project, located near the confluence of the Ohio and Mississippi Rivers, has successfully incorporated similar concepts to limit erosion and scour (http://mvs-wc.mvs.usace.army.mil/thompson/projectdescription.htm).

Photograph V-5. Aerial View of Merriwether-Cherokee Revetment Site in Lake County, TN
The photo on the left shows the area before the flood of 2011. Note the narrow band of trees along portions of the Mississippi River bank. The photo on the right is an aerial view of the same revetment site during the flood of 2011. Flow moved across areas with little riparian buffer/tree screen. Improved tree screens may have reduced erosion and flow velocities sufficiently to reduce the damage in the area.

Photograph V-6. Damage Caused by Overbank Flow at Presidents Island

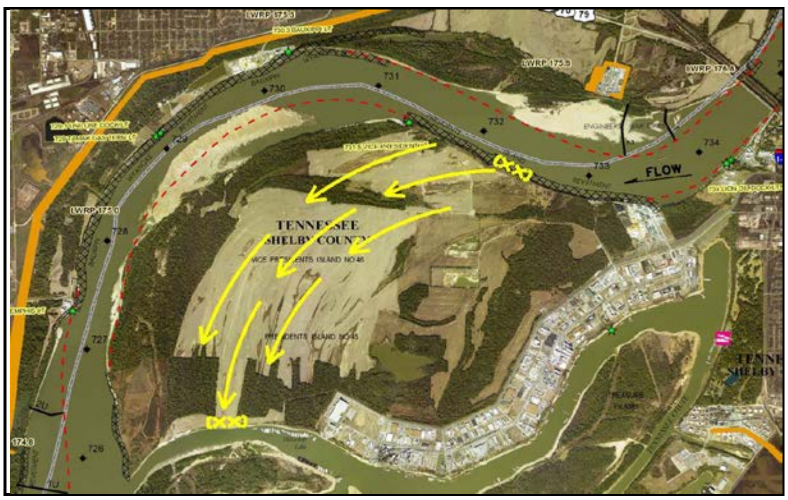


Figure V-5. Annotated Aerial View of the Flow Path of River Water Over President's Island, Shelby County, TN. The flow velocity may have been reduced if a tree screen had been properly installed along the upstream bank of the island.

The introduction of floodwater into the spillway areas caused some mortality to local vegetation. However, the spatial extent of this damage relative to the full vegetated extent in the flooded areas is small, and it is not expected to persist for more than a couple of years. Most terrestrial damage was due to soil scour and the deposition of substantial amounts of sediment along some locations of the floodplain and spillway topographical surface.

While the spillways were engineered for occasional inundation, many contained recreational (e.g., picnic areas, hiking paths, boat launches, and boardwalks) and civil (e.g., roads, culverts, and fences) infrastructure that was damaged by the floodwater during spillway operation. A number of recreational sites have been established within the greater spillway areas or in areas affected by their operation. These sites include approximately 1,093 acres below the BPNM Floodway (e.g., Towosahgy State Park and Big Oak Tree State Park), over 200,000 acres below the Morganza Water Control Structure (e.g. The Atchafalaya Delta Wildlife

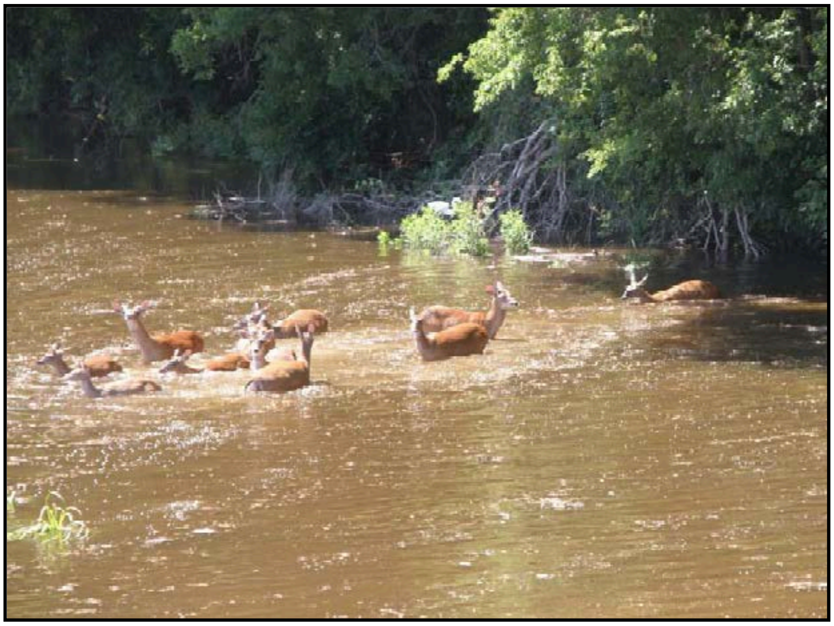
Management Area), and 10 acres below the Bonnet Carré Spillway (e.g. St. Charles Parish Boat Launch and Recreation Area). Large-scale damage to these areas was not reported; however, most of these areas experienced closure or reduced access during and after the flood period. The river discharge introduced to the spillways during their activation did enhance certain recreational activities during and following the flood period, including fishing and crawfish trapping.

ii. Wildlife Resources. When floodwater enters areas unaccustomed to inundation, terrestrial animals flee the area without established escape routes. These fleeing animals run the risk of becoming stranded in areas incapable of supporting their subsistence over the duration of the flood. In general, large-scale flooding promotes crowding or isolating wildlife populations in unflooded regions and may degrade wildlife forage areas until the ecosystem and regional food chains can become re-established. Ground-dwelling animals such as turkey, deer, rabbits, armadillos, feral hogs, and bobcats typically attempt to flee floodwaters while tree-dwelling or semi-aquatic animals often find shelter in trees or slackwater areas with emergent vegetation (photograph V-7).

Photograph V-7. Armadillos Seeking Refuge From Floodwaters

Under non-flash flood, natural flood conditions typical to BLHFs, floodwater rises on the order of inches per day. Under these conditions, animals have the ability to identify the flood risk over time and evacuate to higher ground. While some effort was made to slowly release water into the spillways to minimize its environmental impact, floodwater depths occasionally increased on the order of feet per day, which resulted in observed animal fatalities in a few locations.

Deer fleeing the Morganza Floodway floodwaters were forced to inhabit narrow strips of high ground around levees, emergent trees, and surrounding agricultural fields during the spillway operation (photograph V-8). However, the period of time in which the water control structure was opened was generally not long enough to induce starvation in healthy animals. In the same area, there were some fatalities among interior swamp turkeys. Immediately before the floodway activation, multiple turkeys were fitted with remote tracking devices to record their movement during the floodway operation. Turkeys in areas that experienced rapid flood rise were all observed to methodically search for high ground, traveling along a circular route. Those unable to find high ground died. A concerted effort was made to provide field personnel forms to report black bear sightings. Few bears were seen, but one female bear was killed on the train track running through the Morganza Floodway. There have also been reports that during the spring of 2012, some of the collared and tracked bears are reproducing again this year, suggesting that they lost their cubs last year during the flood, as black bear generally reproduce only after their cubs are 2 years old.



Photograph V-8. Deer Exiting Morganza Floodway During Its Activation

Flooding likely disturbed the nesting activities of the interior least tern, which typically locate their nests on isolated sandbars near the river channel banks, along with other birds that rely on river resources. Flooding inundated nearly all channel bars within the LMR during the flood period. This flooding may have constrained seasonal breeding but did not likely result in large-scale avian fatalities.

b. Aquatic Resources

i. Water Resources. Appendix F, *Environmental and Cultural Resources* of this report contains the results of the water quality sampling conducted by the USGS in coordination with the Corps during the 2011 Flood. Although the sampling occurred at the routine NASQAN sampling sites, in many cases the sampling frequency was increased during the flood. The location of sampling areas is listed in table V-4. The exceptionally high floodwaters of 2011 did not significantly alter the concentration of fluvial sediment, nutrients, and pesticides within the flow of the LMR beyond the mean annual values typical for spring and summer. However, because of the extreme river discharges, the overall mass flux of these constituents did reach record levels. Within the Mississippi River, the transport levels of sediment, nutrients (e.g., nitrogen and phosphorus), and pesticides did not trend with discharge and showed a general tendency to decrease in time within the flood period. Within the spillways, these constituents did display a positive relationship with discharge, but their concentrations were less than that measured in the river at monitoring locations both upstream and downstream of the spillway location. Table V-4 displays averaged and maximum water quality values for four locations along the LMR and the three spillways estimated over the flood period. Also shown are values of the total mass flux for certain contaminants and sediment; however, these flux values were estimated over a shorter time period (as defined in the table legend). The suspended sediment and total nitrogen values shown for the BPNM Floodway were collected during a single time period following the initial activation of the spillway.

Table V-4. Water Quality Values Measured Within the LMR During the 2011 Flood Period

		NUTRIENTS		PESTICIDES
Location	**Suspended Sediment**	**Total Nitrogen**	**Phosphorus**	**Atrazine and Metlachlor**
Mississippi River at MVK, MS	**max -** 164 mg/L **avg -** 126 mg/L 18,800,000[1]	**max -** 2.8 mg/L **avg -** 2.17 mg/L 262,000 [1]	**max** 0.24 mg/L **avg -** 0.19 mg/L 26,200 [1]	**max -** 1.51 µg/L **avg -** 0.88 µg/L
Mississippi River at St. Francisville, LA	**max -** 179 mg/L **avg -** 103 mg/L	**max -** 2.70 mg/L **avg -** 2.07 mg/L	**max -** 0.27 mg/L **avg -** 0.19 mg/L	**max -** 1.43 µg/L **avg -** 0.87 µg/L
Baton Rouge, LA	**max -** 168 mg/L **avg -** 133 mg/L	**max -** 2.8 mg/L **avg -** 2.03 mg/L	**max -** 0.21 mg/L **avg -** 0.17 mg/L	**max -** 1.41 µg/L **avg -** 0.70 µg/L
Mississippi River at Belle Chase, LA	**max -** 206 mg/L **avg -** 149 mg/L	**max -** 2.8 mg/L **avg -** 2.13 mg/L	**max -** 0.27 mg/L **avg -** 0.22 mg/L	**max -** 1.25 µg/L **avg -** 0.83 µg/L
BP NM Floodway	150 mg/L [3]	2.65 mg/L [3]		0.6 µg/L [4]
Morganza Floodway	**max -** 31 mg/L **avg -** 16.5 mg/L 404,000 [1]	9,930 [1]	900 [1]	
Bonnet Carré Spillway	**max -** 177 mg/L **avg -** 105 mg/L 2,307,294 [1, 2]	36,182 [1, 2]	3,342[1, 2]	

[1] values are total estimated flux during the month of May;
[2] during 44 flood days spanning May and June in metric tons;
[3] measured during the initial levee activation;
[4] for Atrazine during the month of May only.

Of some interest are the results of the water quality data for the Atchafalaya Basin. Over 1,000 oil wells were inundated by the floodwaters introduced by the Atchafalaya River and the Morganza Floodway. Samples were collected for gasoline, oil and grease, and petroleum hydrocarbons upstream and downstream from the wells. On May 23, 2011, there was a slightly higher concentration of gasoline detected in the downstream waters, but by the next week, the concentration was higher in the upstream waters. Oil and grease levels were virtually identical upstream and downstream, and there were no detects of petroleum hydrocarbons, indicating that the efforts to shut down and secure the wells prior to inundation were successful. Also, it is interesting to note that during May, 2011, the total load of nitrate plus nitrite decreased slightly between the inflow at the ORCC and the Morganza Floodway, and the outflow at Wax Lake and Morgan City, indicating the possibility of denitrification occurring while the river waters were in contact with the forested wetlands in the Atchafalaya floodway; however, over the same time period, the suspended sediment loads and the total phosphorus loads increased, suggesting that the flood flows caused the resuspension of sediments and adsorbed phosphorus during the flood.

The floodwater released through the Bonnet Carré Spillway entered the coastal waters of southeastern Louisiana and southern Mississippi through Lake Borgne and Lake Pontchartrain. The river water was much colder, much less saline, and contained much higher nutrient loads than the surrounding coastal water, and significantly altered the regional water chemistry in Lake Pontchartrain, and through Mississippi Sound all the way to the area off shore from Biloxi, MS. Coastal waters that typically had salinity levels near 13.0 parts per thousand (ppt) experienced levels as low as 1.0 ppt until mid summer 2011 (figure V-6). The high nutrient loads caused excess phytoplankton (i.e., algae) growth along coastal Louisiana and Mississippi. Freshwater algal species found the Mississippi Department of Marine Resources in Mississippi Sound included *Pediastrum* spp. and *Scenedesmus* spp. and a USGS contractor (The Academy of Natural Sciences of Philadelphia) counted bloom levels of cyanobacteria, likely *Woronichinia.*

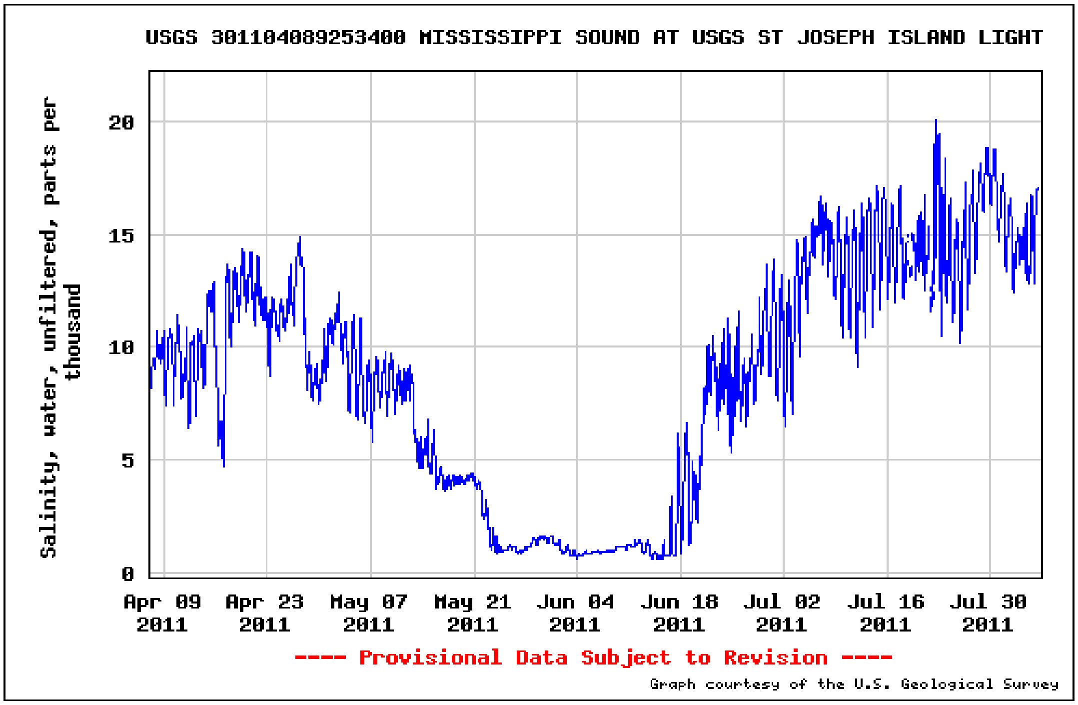


Figure V-6. USGS Plot of Measured Sea Water Salinity at Mississippi Sound During the Flood Period
Salinities were in the range of 10 to 15 ppt, dropped to only about 1 ppt during the opening of the Bonnet Carré Spillway (5/9/2011), then recovered back to the 15 ppt after the spillway was closed (6/20/2011). This particular gaging station was nearly 40 miles away from the spillway, providing some sense of the spatial extent of the effects of the 2011 Flood.

The death and decaying process of large volumes of algae depletes the dissolved oxygen in the water in the vicinity of the algae bloom, which leads to hypoxic conditions and sea life mortality. It is hypothesized that the large, continuous discharge of river water into Lake Pontchartrain during the flood period effectively flushed the introduced freshwater and nutrients through the lake into Mississippi Sound (photographs V-9 and V-10 and figure V-7). This may have caused the hypoxic conditions to form in the estuarine areas. Details on this sampling effort, as well as information on phytoplankton community composition and comparisons between the 2008 and 2011 events are presented in the paper in Appendix F.

Photograph V-9. Aerial Photo of Algae Bloom and Mississippi Department of Marine Resources Boat Collecting Phytoplankton Samples on June 27,2011

Photograph V-10. Turbidity off the Coast of Mississippi Believed
To Be Due to the Mixing of Fresh and Salt Water, June 22, 2011

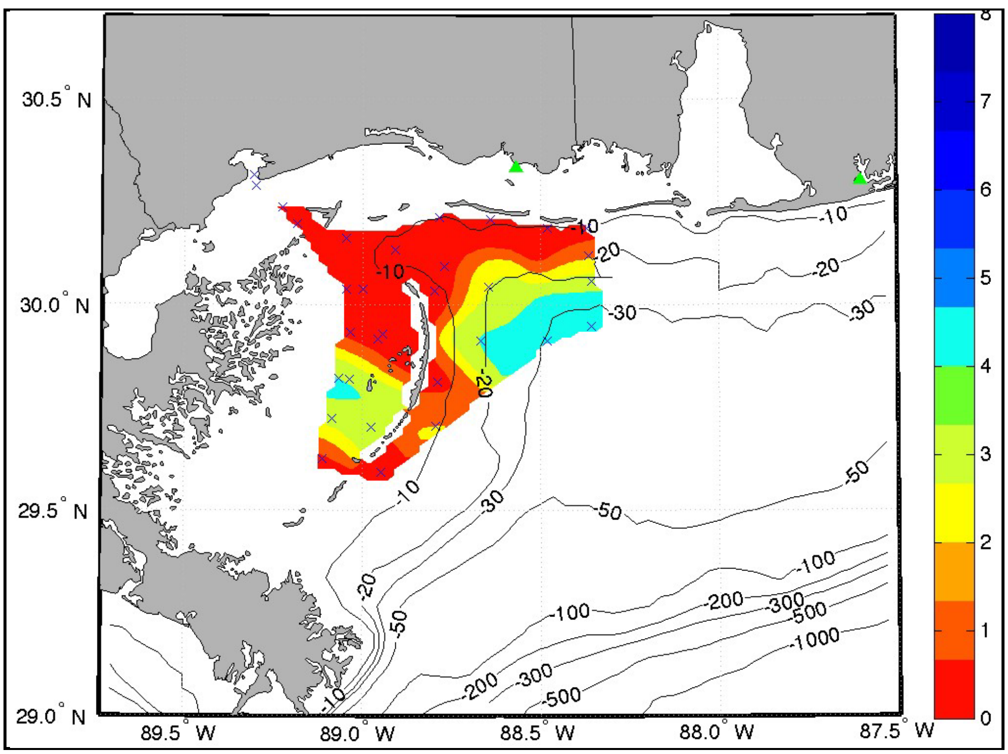


Figure V-7. Survey of Bottom Water Hypoxia in August 2011 in Mississippi Sound
(Dr. Steve Howden, Department of Marine Science, University of Southern Mississippi)
The scale bar (right hand side) shows bottom water dissolved oxygen concentrations (mg O_2/L). This data would suggest that the nutrient rich freshwater from the river encouraged algal growth and when those algae died, their decomposition exhausted the available dissolved oxygen in the coastal waters.

ii. Fisheries. Most aquatic life along the Mississippi River and side channels has evolved behavior to mitigate the effects of floods (e.g., seeking refuge in side channels and pools). However, some fish fatality occurred due to drastic drops in river water temperature due to very large rainstorms during the flood period. Quick changes in water temperature may inhibit the natural mixing within the water column, which creates temporary zones of low oxygen incapable of supporting life (i.e., hypoxia). The floodwater within the spillway areas disrupted the habitat of some commercially viable species that lived in the area, such as crawfish. However, it is unclear if any of these species' populations were significantly affected.

One of the species of concern in the Mississippi River is the pallid sturgeon. There is little scientific literature describing how pallid sturgeon respond to distributary channel flows (i.e., flow diverted into spillways). For example, it is unknown if secondary channels are actively sought for refuge and increased food sources during main channel floods or if they are avoided (USFWS, 2009). Because of this, it is unknown if the sturgeon observed within the spillway had entered it on purpose or were entrained when swimming nearby. Pallid sturgeon favor turbid water and do consume floodplain food sources, such as macroinvertebrates, as well as invertebrates and small fish living in the main channel (USFWS, 2010). Recent investigations of the BPNM floodway have not identified any topographic or hydrographic features that would appear to attract the sturgeon to the vicinity, other than functioning as a large side channel. Prior floods have shown that pallid sturgeon are entrained by the Bonnet Carré Spillway. Pallids require freshwater, and once the spillway is closed, Lake Pontchartrain returns to a brackish salinity, which would limit pallid sturgeon viability. Therefore, it is necessary to attempt to "rescue" the pallid sturgeon trapped in the Bonnet Carré Spillway and Lake Pontchartain and return them to the Mississippi River. Pallid sturgeon may also be entrained by the ORCC; however, a significant population of pallids lives in a scour hole downstream from the ORCC. It is believed that the length of the freshwater extent of the Atchafalaya River is too short to allow the successful reproduction of pallid sturgeon, thus making the population living downstream of the structure non-viable.

In coastal areas spanning from Lake Pontchartrain and Lake Borgne through Mississippi Sound, and beyond Biloxi, MS, the dissolved oxygen and salinity levels dipped below that required for many aquatic species. Species unable to flee the affected waters, such as sessile animals like oysters, experienced high levels of mortality. For example, mature oysters reefs along Mississippi Sound experienced mortality rates exceeding 85 percent. Preliminary reports estimate that the economic cost of the flood damage (caused by spillway use) to the entire oyster industry as approximately $60 million. The degraded quality of the coastal waters was estimated to have reduced the commercial Mississippi blue crab harvest by approximately 50 percent for 2011 (May to August). The regional brown shrimp population appeared to have been unaffected by the influx of floodwater. Information was requested about the impacts to Louisiana oysters, but the Louisiana state resource agencies declined to comment on their situation.

The Louisiana Department of Wildlife and Fisheries has reported (R.T. Ruth, personal communication) that there was the movement of silver carp from the Mississippi River, through the freshened waters of Lake Pontchartrain, into the Pearl River system. Additional documentation of damages associated with the flood in the Atchafalaya Basin can be found in the report *2011 Atchafalaya Basin Inundation Data Collection and Damage Assessment Project* authored by Carlson, Horn, Van Biersel, and Fruge.

c. Cultural Resources. Damage to archeological sites within the major spillways, during their activation, has largely been limited to the BPNM Floodway. Activation of the BPNM floodway requires detonation of explosives to remove an earthen levee between the floodplain and the spillway entrance. This type of sudden activation creates a near-instantaneous release of a large volume of floodwater into the spillway that has the potential to severely scour soil and sediment along the spillway surface. Scour can destroy archaeological site integrity and expose both Native American and Euro-American historic burials at this site. The activation of the BPNM floodway caused deep scouring around the north end of Birds Point frontline levee. At this location, scouring damaged a previously undetected, late-Mississippian archeological site (National Register site number is 23MI136) (photograph V-11). The flow entrained and transported prehistoric human skeletal remains and related artifacts (e.g., faunal material, pottery pieces) over a seven-acre area. This inadvertent discovery was identified during the immediate post-flood period (June 2011) during the early stages of the "Operation Make Safe" levee restoration.

Photograph V-11. Large Areas of Soil Scour After Spillway Operation at the BPNM Floodway
In this area, soil erosion led to the exposure of a previously unidentified burial site (23MI136).

The Bonnet Carré Spillway contains sections of two cemeteries (i.e., Kugler cemetery and Kenner cemetery) but no scour was observed within their areas. Spillway maintenance activity accidently exposed buried bodies within the Kugler cemetery in 2008. There are no identified archeological sites within the Morganza Spillway.

F. DAMAGES PREVENTED

The existing MR&T Project (whether Scenario 1 or Scenario 4) prevented approximately $234 billion in urban and agricultural flood damages (compared to Scenario 3) during this single event. Without a FRM system in place, approximately 1.45 million residential and commercial structures would have been impacted. With the MR&T System, this decreases to 21,203 structures.

In comparison, the MR&T Project (reservoirs only, Scenario 2) prevented approximately $11.8 billion in urban and agricultural flood damages (compared to Scenario 3) during the 2011 Flood, which results to only a 5 percent reduction in total flood damages. Estimates of flood damages prevented for the four hydrologic scenarios are presented by Corps District in Appendix G, *Economics.* For Scenarios 1 and 4, the flood damage prevented estimates are the same since the hydrographs for these two scenarios were the same. Flood damages prevented for Scenarios 1f and 4 reduced flood damages by approximately 98 percent.

1. Reduced Impact on Population. Estimates on the number of people protected by the MR&T Project during the 2011 Flood are presented in tables in Appendix G, *Economics*. The results of the damage analysis showed that 98 percent of the overall population was spared from the adverse impacts of flooding. The same amount of protection was afforded with Scenario 1 as 4. As shown, the majority of the reduced impacts occurred in MVN, MVK, and MVM.

2. Project Effectiveness. Project effectiveness is measured by the amount of flood risk reduced by the project, or in terms of its percent in flood risk reduction (FRR). This also relates to the degree of protection (DOP) afforded by the project. The results of project effectiveness from flood damages prevented for each scenario are displayed in table V-5. Based on the results of the flood damage evaluation, the FRR for Scenarios 1 and 4 resulted in a 98 percent DOP while Scenario 2 (reservoirs only) provided only minimal protection in terms of FRR with a 5 percent DOP.

3. Overview. Without the MR&T Project in place (i.e., Scenario 3) total flood damages in the seven-state impacted area would have been over $237 billion. Furthermore, the Project provided a 98 percent flood risk reduction. Based on the significant influence of the Mississippi River on surrounding economies, it is not hard to grasp the importance of the main stem levee system to the region. Protecting approximately 53 million acres of land in the States of Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee of the lower Mississippi River valley, it has the task of trying to contain one of the oldest and most powerful natural resources in the world—the Mississippi River.

Table V-5. Summary of Damages Prevented and Effectiveness of MR&T Project [1]

		Without MR&T Project (Scenario 3) [2]	**With-Project Conditions**		
Scenario	**With-MR&T Project Description**	**Total Damages** (million $)	**Total Residual Damages** (million $)	**Total Damages Prevented Benefits** (million $)	**FRR** [3]
1	**As Occurred 2011** (minor deviations in reservoir operations)	$237,152,397,000	$2,863,843,000	$234,288,554,000	98 %
2	**With Reservoirs, But No Levees**	$237,152,397,000	$225,315,506,000	$11,836,891,000	5%
4	**As Designed 2011** (no deviations in reservoir operations in 2011)	$237,152,397,000	$2,863,843,000	$234,288,554,000	98 %

[1] values expressed in 2012 prices

[2] the without-project condition

[3] percent of FRR from project implementation; also referred to as DOP

SECTION VI

POST-FLOOD RECOVERY

A. OVERVIEW OF SYSTEM RECOVERY

While 2011 floodwaters were still moving through the MR&T System, MVD began moving out with post-flood recovery efforts to assess damages and identify work needed to restore the system to pre-flood conditions. An Interagency Recovery Task Force (IRTF), comprised of Federal- and state-led agencies, was formed and began meeting to develop solutions for short- and long-term recovery, and communication efforts. After Action Reports (AARs) were generated to document the effectiveness of the 2011 emergency response, strengths and weaknesses of the MR&T operation, and recommendations for future improvement. MVD also moved out with a system performance evaluation of the MR&T that developed into this PFR, focused on assessing the performance of the system and identifying opportunities for improvement. Teams of engineers and levee and water management experts began examining every component of the MR&T system and produced Damage Assessment Reports (DAR) that assessed damages, identified elevated risks, and laid out plans for needed repairs. Information in the DARs was used to develop an overall plan for sequencing needed MR&T repair efforts, and recovery construction activities moved out. Finally, due to the damages and elevated risks that remained in late 2011, the Corps formed a 2012 Flood Season Preparedness Team to better prepare for the upcoming flood season by identifying key risks within the MR&T System, how these risks were being addressed, and effectively communicated this information to partners and stakeholders through new regional tools and a Mississippi Valley Flood Preparedness Workshop.

B. 2011 FLOOD AFTER ACTION REPORTS

After action reports are generated following major events to determine and record operation successes and lessons learned. Engineering Pamphlet 500-1-1 contains the guidance for AARs. These reports are generated through critique sessions that may be requested by divisions, districts, or HQUSACE. In the case of the 2011 Flood, AARs were compiled using information including public meetings and interviews. The AAR is a summary of disaster operations and interagency coordination. Its intended use is to improve the conduct of future operations, as well as serving as the consolidated historical record of the disaster. After action reports include a discussion of the emergency situation, the types of assistance provided, coordination with FEMA and other agencies, effectiveness of the response, strengths and weaknesses of the operation, specific problems and suggested solutions, general appraisal and comments, conclusions, and recommendations.

Subsequent to the 2011 Flood, the following AARs were gathered:

- 2011 Flood AAR MVP EOC, July 2011
- 2011 Flood AAR MVS EOC, May 2011
- 2011 Flood AAR MVM EOC, September 2011
- 2011 Flood AAR MVK EOC, September 2011
- 2011 Flood AAR MVN EOC, October 2011
- 2011 Flood AAR ERDC

Information from the AARs was used throughout this Report to help document the operation and performance of the MR&T System. The AARs helped to underscore the changing technologies that are used to fight floods ranging from advanced mapping to the use of Freeboard for documentation purposes. The AARs also reveal that seemingly minor logistical issues such as vehicle availability and timesheet management and routine communications can disrupt the more technical functions of the flood fighting. Good documentation in AARs can better prepare future flood fight efforts to overcome these hurdles and lead to better operation and management of the MR&T System in the future. These publications can be found in Appendix E, *Communications and Collaboration*.

C. DAMAGE AND REPAIR NEEDS

1. Introduction. As the waters rose throughout the 2011 flood fight, damage assessment teams inspected the levees and other MR&T System Components. The teams identified seeps, boils, slides and other anomalies while documenting and uploading information to be used to prepare DARs and to document and prioritize repair needs. Once the waters receded, these teams continued their assessments and prepared documents which identified the location, nature, extent, repair alternatives, and estimated preliminary repair costs for these damaged areas. All MR&T assessments utilized a DAR format to keep the data gathering and supporting information consistent. Forty-four separate DARs were developed to ensure that all levee reaches, structures and navigational river miles affected by this event were inspected and thoroughly documented (Appendix B, *Levees and Floodwalls*). The reports were submitted to an oversight team to ensure the consistency, functionality and quality of the final product.

Risk classifications in accordance with FRAGO 1 to OPORD 201150 were utilized to categorize all Operation Watershed – Recovery (OW-R) repair projects into one of the four primary classes. The *2012 Flood Season Preparedness and Emergency Response Summary* section of Appendix J, *MR&T System Recovery Strategy,* provides further details on the classification system and associated definitions for risk factors of "Failure Likelihood" and "Consequences" established by HQ and applied by MVD. Section VI. D. of this report also includes additional discussion on how this risk classification process was part of the overall MR&T system recovery strategy. This classification system was utilized to establish a Relative Risk Matrix, as shown in Appendix J, *MR&T System Recovery Strategy*, figure VI-1.

CRITICAL REPAIRS

Failure Likelihood				
High	**Class IIIb**	**Class II**	**Class II**	**Class I**
Moderate	Class IV	Class IIIa	Class II	Class II
Low	Class IV	Class IIIa	Class IIIa	Class II
Remote	Class IV	Class IV	Class IV	Class IIIb
	Level 0	Level 1	Level 2	Level 3

Consequences

NON-CRITICAL REPAIRS

Figure VI-1. OW-R Flood Damage Risk Matrix

Projects in Classes I, II and IIIa were designated as Critical Repairs and those in Classes IIIb and IV were designated as Non-Critical Repairs (figure VI-1). A regional team utilized this classification process to establish a regional "1-n" prioritization of critical repair projects, referenced as Phase I (Aug 2011) and Phase II (Oct 2011) Critical Repair Prioritizations. Class IIIb and IV items were also reviewed at the regional level and categorized as Phase III (Jan 2012) and Phase IV (Feb 2012) Noncritical Repairs. Based upon the severity of the damages and the guidance provided by the FRAGO classification guidance, a regionally prioritized list of projects (Appendix J, *MR&T System Recovery Strategy)* was developed by MVD. Figures VI-2, VI-3, and VI-4 illustrate the damage locations and their associated risk classifications within MVM, MVK, and MVN, respectively. Larger versions of these figures are located at the end of the report in Plates 1-3.

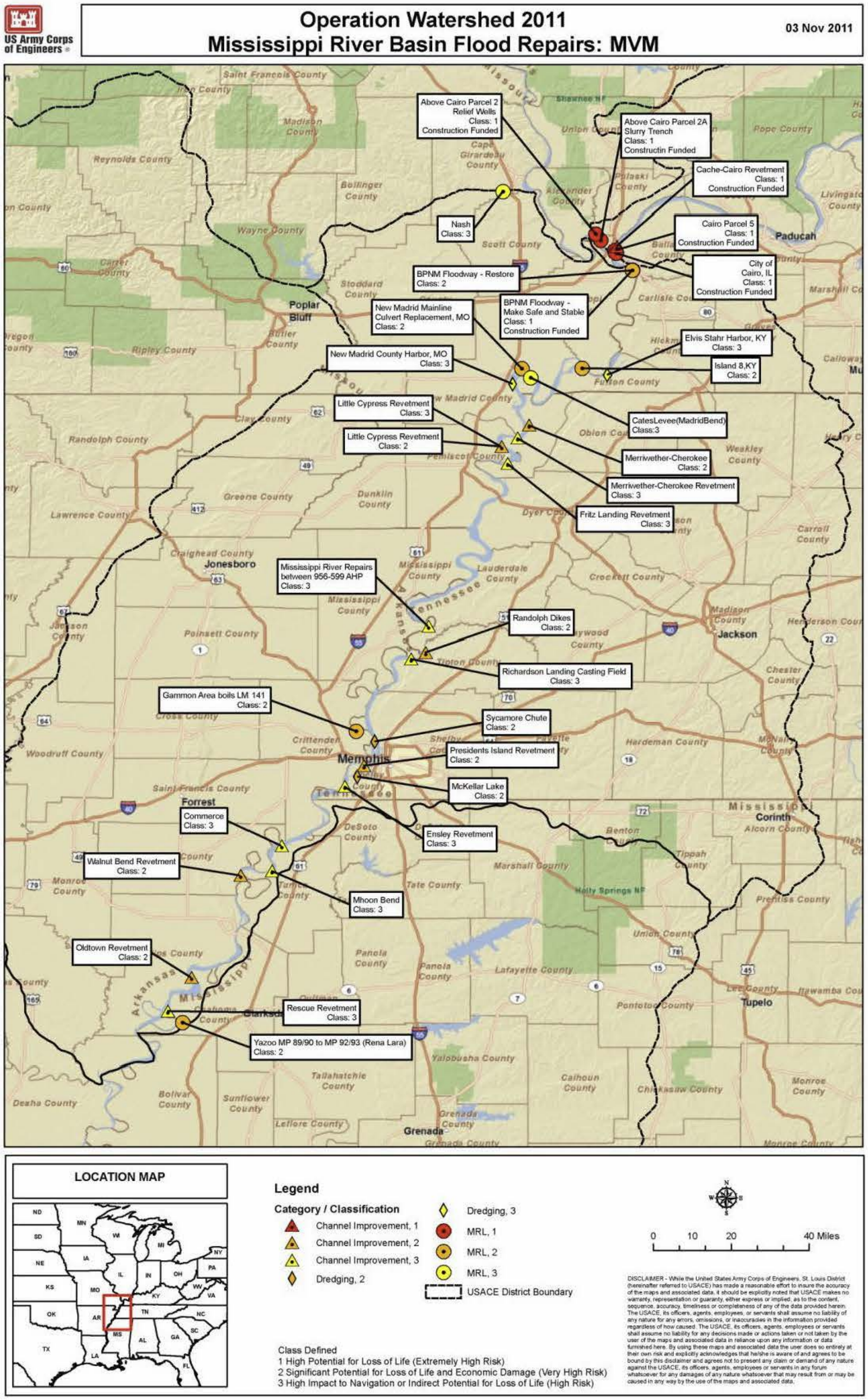


Figure VI-2. Damaged MR&T Components and FRAGO Risk Classification Within MVM

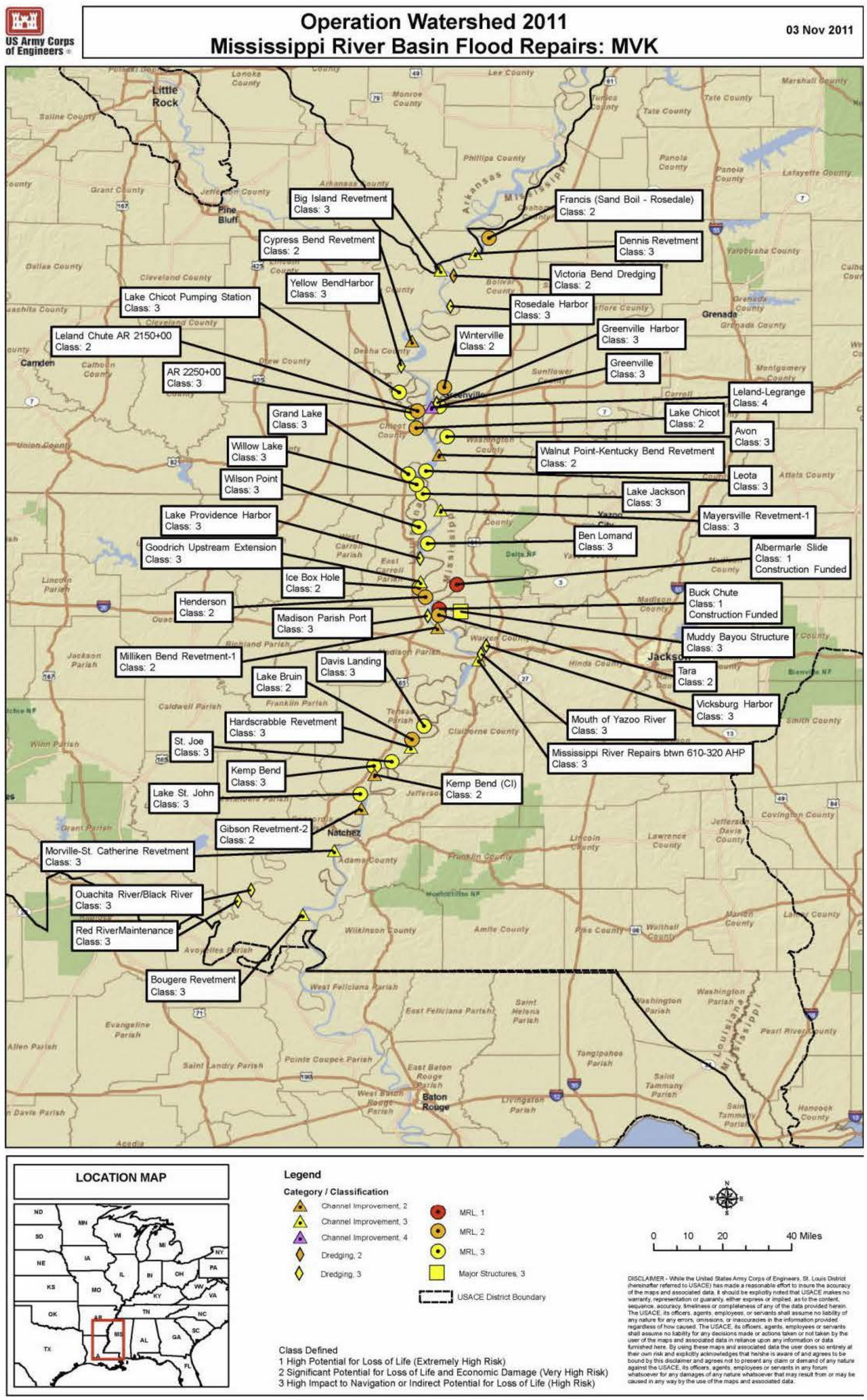


Figure VI-3. Damaged MR&T Components and FRAGO Risk Classification Within MVK

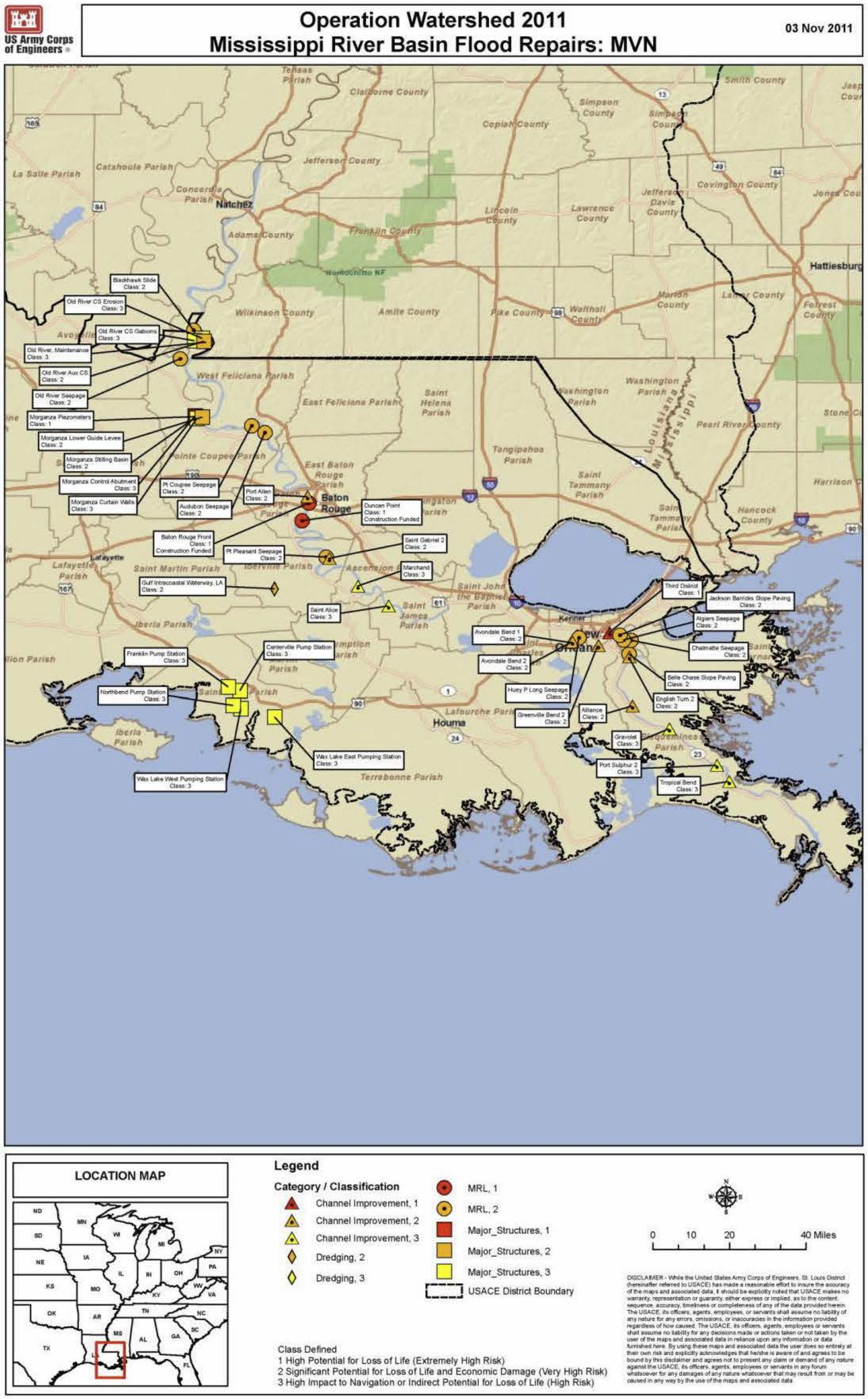


Figure VI-4. Damaged MR&T Components and FRAGO Risk Classification Within MVN

2. Reservoirs. The only MR&T reservoir that experienced flood damages was Wappapello Lake. As a result of record rainfall, multiple peak inflows of greater than 100,000 cfs raised Wappapello Lake to a record pool elevation of 400.04 NGVD on May 3 (0.95 feet above the previous record and 5.30 feet above the auxiliary spillway). The spillway, exit channel, roads, and utilities incurred damages and spillway overtopping caused significant downstream damages. The overall damage assessment rating for this post-flood system was Minimally Acceptable. Damage assessments identified 7 Unacceptable deficiencies and 15 Minimally Acceptable deficiencies. Unacceptable deficiencies included dam safety, inspection, exit channel, spillway, roads, and utilities. Each item was damaged and was either not functional or had a high potential of failure.

- **Unacceptable Inspection.** Components of the outlet works were damaged by the flood and in need of inspection resulting in an initial rating of unacceptable. Inspection is only possible during low lake stages when bypass pumping can divert the entire outflow around the outlet works. In March 2012, this condition was met, inspection was conducted, and minimal damage was found.

- **Unacceptable Exit Channel**. Both deficiencies relate to scoured sections of revetment downstream of the gatehouse exit channel. If not repaired, this failure will lead to continued scour and deterioration potentially compromising the dam.

- **Unacceptable Spillway.** 2,000 feet of channel immediately downstream of the spillway structure was severely eroded during spillway operation, creating an extreme risk to public safety. This deficiency is a critical life safety concern—the steep, unstable banks and rock outcrops present an unsafe condition to general public.

- **Unacceptable Road.** The entire road (150 feet asphalt;1200 feet gravel), parking lots (60 feet x 30feet asphalt; 430 feet x 50 feet gravel), and boat ramp were scoured out and were covered in debris, and the trail head was destroyed. The road and boat ramp are the only access points to the St. Francis River and are critical for emergency access. This deficiency was a critical life safety concern, but interim measures by the project to warn the public and to cordon off the area have been implemented to reduce risks.

- **Unacceptable Utilities.** The line providing commercial power to the gate house was exposed by scour due to operation of the spillway. This is an imminent failure because the exposed electric utility line could be damaged and power lost to the gatehouse. A loss of power to the gatehouse would result in the inability to operate the gates and therefore, the ability to manage the water level in the reservoir.

Minimally acceptable deficiencies included natural resources, recreation areas, exit channel, spillway, roads, and utilities. The overall project is still able to function as intended and was not in danger of failing, consequently receiving a Minimally Acceptable rating.

3. Levee and Floodwall Systems. Between June 1 and September 30, 2011, Damage Assessment Inspections were performed for each levee System within the MR&T System. Each inspection resulted in a DAR which grouped damages into remediation/repair projects, and preliminary repairs and associated cost estimates were developed. Based upon the severity of the damage/deficiency and the guidance provided in the FRAGO classification guidance, MVD developed a prioritized project list. The DARs and the prioritized project list were reviewed and summarized as a part of the data collection process for this report.

Repairs rated at FRAGO classifications I, II, and IIIa were considered critical and others non-critical. Critical repairs are those that would receive earlier funding to implement immediate risk reduction. These projects remediate issues identified during the 2011 event that are likely to cause failure prior to a 25-year flood event. Table VI-1 provides a prioritized listing of FRAGO Classification 1 needs for the MR&T System Levees and Floodwalls. Non-critical damages are being repaired after critical repairs are addressed. These projects also remediate issues identified during the 2011 event that could possibly lead to failure prior to a 25-year event, but they carry lower risk than other damaged areas. Table VI-2 provides a prioritized listing of FRAGO Classification 2 and 3 needs for the MR&T System Levees and Floodwalls.

Table VI-1. FRAGO Classification 1 Projects for Mississippi River Levees and Floodwalls

District	Item	System	Failure Likelihood	Consequence	Work Performed	Construction Completion	Est. Cost ($1000)
MVM	BPNM Floodway - Make Safe & Stable	#4016	H	3	Levee Rebuild	01 Dec 11	$15,000
MVM	City of Cairo, IL	#4001	H	3	Relief Wells	30 Oct 13	$3,000
MVM	Cairo Parcel 5	#4001	H	3	Seepage Berm/ Slurry Trench	30 Nov 13	$7,000
MVM	Above Cairo Parcel 2A - Relief Wells	#4001	H	3	Relief Wells	20 Jan 13	$1,500
MVM	Above Cairo Parcel 2 - Slurry Trench	#4001	H	3	Slurry Trench	27 Jan 13	$5,500
MVK	Buck Chute	#5921	H	3	Seepage Berm/ Relief Wells	31 Jul 12	$2,640
MVK	Albemarle Slide	#5921	H	3	Seepage Berm	31 Jul 12	$1,006
MVN	Duncan Point	#4401	H	3	Seepage Berm	10 Aug 12	$8,850
MVN	Baton Rouge Front	#4401	H	3	Floodside Berm	30 Apr 12	$1,762

The term “system” is used in the following pages of this report section primarily to refer to multiple Levee and Floodwall systems or areas that make up the overall MR&T System. In other sections of the Post-Flood Report smaller portions of the MR&T System are referred to as sub-systems, but the term system was used here (instead of sub-system) to be consistent with the naming convention used in the DAR process. For example, components near the Cairo, IL area are referred to as “System #4001 – Mississippi and Ohio River Levees at Cairo and Vicinity.”

Table VI-2. FRAGO Critical Repair Classification 2 & 3 Projects for Mississippi River Levees and Floodwalls

District	Item	System	Failure Likelihood	Consequence	Work Performed	Construction Completion	Estimated Cost ($1000)
CLASSIFICATION 1 PROJECTS							
MVK	Francis (Sand Boil - Rosedale)	#5921	M	3	Relief Wells	31 Dec 12	$474
MVK	Winterville	#5921	M	3	Relief Wells	31 Dec 12	$510
MVM	Yazoo MP 89/90 to MP 92/93 (Rena Lara)	#5921	M	3	Relief Wells	31 Dec 13	$3,000
MVK	Tara	#5921	M	3	Seepage Berms/Wells	31 Dec 14	$2,758
MVN	Chalmette Seepage	#4405	M	3	Sheetpile Cutoff	05 Mar 12	$2,268
MVN	Old River Seepage	#4415	M	3	Seepage Berm	28 Sep 13	$21,200
MVN	Audubon Seepage	#4425	M	3	Drainage Repair	30 Dec 12	$233
MVM	Island 8, KY	#4003	M	2	Relief Wells	30 Sep 14	$5,500
MVM	BPNM Floodway - Restore	#4016	M	2	Levee Repair	[1]	$15,000
MVM	Gammon Area Boils	#4002	M	2	Relief Wells	31 Dec 13	$2,500
MVK	Lake Bruin	#5901	L	3	Relief Wells	31 Dec 13	$765
MVK	Leland Chute AR 2150+00	#5901	L	3	Seepage Berm	31 Dec 13	$2,922
MVK	Lake Chicot	#5901	L	3	Relief Wells	31 Dec 13	$587
MVK	Henderson	#5901	L	3	Relief Wells	31 Dec 13	$1,836
MVK	Ice Box Hole	#5901	L	3	Relief Wells	31 Dec 13	$587
MVN	Pt. Coupee Seepage	#4425	L	3	Seepage Berm	07 Apr 15	$49,626
MVN	Pt. Pleasant Seepage	#4425	L	3	Seepage Berm/ Relief Wells	26 Jul 16	$147,866
MVN	Algiers Seepage	#4452	L	3	Seepage Cutoff Wall/Berm	25 Sep 14	$7,888
MVN	Blackhawk Slide	#4415	L	3	Rebuild Slope (Fill or Rock)	01 Aug 11	$3,203
MVN	Jackson Barracks Slope Paving	#4405	L	3	Repair Cracked Slope	01 Mar 12	$126
MVN	Huey P. Long Seepage	#4452	L	3	Sheetpile Cutoff	04 Sep 13	$10,044
MVN	Belle Chase Slope Paving	#4410	L	3	Place Rock, Permanent Repair Under the Co-located Project	28 Feb 12	$116
CLASSIFICATION 2 AND 3 PROJECTS							
MVM	Cates Levee (Madrid Bend)	#4004	L	2	Levee Rebuild	31Dec13	$436
MVK	Avon	#5921	L	2	Seepage Berm/ Relief Wells	30 Sep 14	$927
MVK	Willow Lake	#5901	L	2	Relief Wells	30 Sep 15	$2,936
MVK	Leota	#5921	L	2	Relief Wells	30 Sep 14	$438
MVK	Lake St. John	#5901	L	2	Relief Wells	31 Dec 14	$973
MVK	Davis Landing (Lake St. Joseph)	#5901	L	2	Relief Wells	31 Dec 14	$1,850
MVK	Lake Jackson	#5921	L	2	Relief Wells	30 Sep 14	$795
MVK	Grand Lake	#5901	L	2	Relief Wells	30 Sep 15	$617
MVK	Greenville	#5921	L	2	Relief Wells	30 Sep 14	$438
MVK	St. Joe	#5901	L	2	Relief Wells	31 Dec 14	$3,383
MVK	Wilson Point	#5901	L	2	Relief Wells	30 Sep 15	$974
MVK	AR 2250+00	#5901	L	2	Structure/ Relief Wells	30 Sep 15	$438
MVK	Kemp Bend	#5901	L	2	Relief Wells	31 Dec 14	$260
MVK	Lake Chicot Pumping Station	#5901	L	2	Structure/ Relief Wells	30 Sep 15	$795
MVM	Nash Levee	#4021	L	2	Relief Wells	31 Dec 13	$1,500
MVK	Ben Lomand	#5921	L	1	Relief Wells	30 Sep 14	$617

[1] Scope of this project has not yet been determined and therefore we do not yet have a complete date

The following sections describe the damages incurred by each levee System as well as the deficiencies revealed in each System as a result of the 2011 high water event. More details on these damages, deficiencies, and proposed remediation are included in the DAR for each System. Only systems with items identified as FRAGO Class 1, 2 or 3 are included. The levee inspection ratings are defined as follows:

- **Acceptable System.** All items or components are rated as Acceptable.
- **Minimally Acceptable System.** One or more items are rated as Minimally Acceptable or one or more items are rated as Unacceptable and an engineering determination concludes that the unacceptable items would not prevent the segment / system from performing as intended during the next flood event.
- **Unacceptable System.** One or more items are rated as Unacceptable and would prevent the segment / system from performing as intended, or a serious deficiency noted in past inspections (which had previously resulted in a minimally acceptable system rating) has not been corrected within the established timeframe, not to exceed 2years.

a. Memphis District

i. SYSTEM #4001 - Mississippi and Ohio River Levees at Cairo and Vicinity. Four areas of uncontrolled seepage and sand boils were recorded and defined as impacting the ability of System to perform. In addition, spalls, cracks, leaking joints and possible stability issues were observed in the Cairo floodwall that impacted the ability of the System to perform; however, these damages did not cause the System to breach. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4001 is unacceptable. Prior to the flood, this system was also rated as unacceptable.

The most significant issues observed during the damage assessment inspection were large amounts of seepage along Segments 3 and 5 and multiple issues with the Cairo Floodwall. Seepage in Segment 3 consisted of three large high energy sand boils with sand cones ranging from 8 to 15 feet. In Segment 5, hundreds of small to medium boils 150 to 300 feet from the levee toe were observed (photographs VI-1 and VI-2). Issues with the Cairo Floodwall include tilting/settlement and multiple spalls/cracks with exposed reinforcing steel in some locations.

Photograph VI-1. Aerial View of Completed Sand Boil Ring

Photograph VI-2. Sand Cone Segment 5

ii. SYSTEM #4002 – Commerce, Missouri to St. Francis River. Seven areas of uncontrolled seepage and sand boils, one levee slide, one area of possible overtopping, and two areas of erosion were recorded that were defined as impacting the ability of the System to perform; however, these damages did not cause the System to breach. Considering the observed performance of the System# 4002 and damages that resulted from the event, the overall rating for the post-flood levee System #4002 is minimally acceptable. Prior to the flood, this system was also rated as minimally acceptable.

System Performance during the 2011 event revealed deficiencies in seepage conditions, levee slope stability and levee height at highway crossings. Seepage and sand boil activity were observed at eight locations within the System. Seven of these seepage areas were defined as impacting the ability of the System to provide FRM during the PDF. The majority of the observed seepage consisted of heavy seepage with pin boils and/or small to medium boils moving moderate amounts of material. One large high energy boil was noted in Segment 17 at levee mile 125.

A drainage ditch located at the levee toe in Segment 25 within the City of New Madrid experienced some bank caving due to erosion of the ditch banks from high interior drainage flow velocities. The roadside ditches at Hwy 57 in Segment 8 and at Hwy 155 in Segment 16 were sandbagged to prevent overtopping. Both of these depressed crossings are several feet lower than the PDF.

iii. SYSTEM #4003 – Mississippi and Ohio River Levees at Cairo and Vicinity. Three areas of uncontrolled seepage and sand boils, one area of scour, one spur levee breach, and a vulnerability with the floodwall not tying properly to high ground were recorded and defined as impacting the ability of the System to perform; however, these damages and vulnerabilities did not cause the System to breach. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4003 is unacceptable. Prior to the flood, this system was rated as minimally acceptable.

System Performance during the 2011 event revealed deficiencies in seepage conditions, height of protection, scour and floodwall/ levee embankment interaction. Three major areas of uncontrolled seepage were observed during the 2011 event:

- In Segment 11 between miles 1/0+00 and 5/35+00, light to medium seepage was observed with some areas having hundreds of pin boils with some small boils;
- In Segment 11 from mile 5/35+00 to mile 15/0+00, the majority of the area had heavy seepage with pin and small boils with at least 3 areas having large to large high energy boils;
- In Segment 14, medium seepage and sand boils were observed between miles 17/40+00 to 18/5+00.

A private spur levee (non-Federal) known as Sheep's Ridge Road overtopped, resulting in a full breach of this spur levee. Approximately 3 miles of levee in the levee System, including the Tiptonville Levee Extension (Segment 58) and two sections of levee intersecting the sleeve levees in Segment 13 had to be raised to prevent overtopping. The most recent survey indicates that much of the Tiptonville extension is below authorized grade.

The Riverside levee slope was significantly scoured due to pumping interior water in the Tiptonville area over the levee. Two holes approximately 20 to 40 feet in diameter and 8 feet in depth developed on the riverside slope.

The upper (east) end of the Hickman Floodwall does not properly tie-in to natural ground. There was a 3- to 4-foot vertical drop at the end of the floodwall down to natural grade resulting in a protection gap. Construction drawings for the Hickman Floodwall (photograph VI-3).dated 1949 show an earthen levee/berm required in this location; however, there is no evidence that it was ever constructed.

Photograph VI-3. Hickman Floodwall

iv. SYSTEM #4004 – Cates Levee System. Two areas of possible overtopping were recorded that were defined as impacting the ability of the System to perform. One breach occurred within this System as a result of these damages. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4004 is unacceptable. Prior to the flood, this system was rated as minimally acceptable.

System Performance during the 2011 event revealed deficiencies in levee height. During the event the Madrid Bend Levee at Cates from mile 0/1 to approx mile 2/27+50 was raised approximately 2 feet and the levee was reinforced at mile 0/1 where it ties to high ground. This portion of the levee performed well after being raised.

The Madrid Bend Levee is a Federal levee that overtopped and breached approximately 1,000 feet from the downstream end of this sleeve levee. The resulting breach is 315 feet in length with an average depth of 15 feet. This portion of the levee is designed to overtop and its purpose is to prevent the Mississippi River from bypassing the New Madrid Bend.

v. SYSTEM #4006 – Mississippi and White Rivers Below Helena System. Four areas of uncontrolled seepage and sand boils and two levee slides were recorded that were defined as impacting the ability of the System to perform. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4006 is minimally acceptable. Prior to the flood, this system was also rated as minimally acceptable.

System Performance during the 2011 event revealed deficiencies in seepage conditions and levee slope stability. Six areas of uncontrolled seepage were observed in this System, four of which were classified as impacting the ability of this System to perform. The observed seepage consisted of sheet seepage, pin boils and small to medium boils moving moderate amounts of material. The two worst areas consisted of a medium boil in a levee toe ditch along the White River Backwater Levee and several medium sand boils at the toe of a 150-foot berm in mile 22 of the Mississippi River Levee.

iv. SYSTEM #4021 – Little River Drainage District of Missouri System. One area of uncontrolled seepage and sand boils and one levee slide were recorded that were defined as impacting the ability of the System to perform. No breach occurred within this System as a result of these damages. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4021 is minimally acceptable. Prior to the flood, this system was also rated as minimally acceptable.

System performance during the 2011 event revealed deficiencies in seepage conditions and levee slope stability. During the 2011 event numerous medium sand boils moving significant amounts of material formed within the relief well collector ditches (photograph VI-4). As a result of the sand boil activity the ditch bank failed in several locations. In addition, a large levee slope stability failure occurred that extended over 100 feet along the levee and had a 3- to 4-foot face.

Photograph VI-4. Sand Boil in Relief Well Ditch

vii. SYSTEM #4016 - New Madrid Floodway Levee System. Six areas of erosion were defined as impacting the ability of the System to perform. Three of these areas are associated with crevasses created in order to operate the Floodway. System #4016 performed as designed during the 2011 event. However, considering the damages that resulted from operation of the Floodway, the overall rating for the post-flood levee System is unacceptable. Prior to the flood, this system was rated as minimally acceptable.

System performance during the 2011 event and prior to operation of the floodway revealed no deficiencies in this levee System. However, extremely high water levels required operation of the BPNM Floodway to relieve pressure on other parts of the MR&T System. Prior to operation of the Floodway, the levee System had to withstand record levels of high water pressures from the riverside. The most significant damages to the levees are associated with the three large segments of the levee that were artificially crevassed with explosives during the operation and with extreme erosion/bank caving specifically in the areas of the upper, center and lower crevasses and the associated overflows. Blue-holes were formed at the upper crevasse and the center crevasse with erosion due to overtopping on large portions of the levees near all the crevassed locations. There was also a large 10 foot deep scour hole, at the landside levee toe located at the northern end of Segment 76 and approximately 85 miles south of the upper crevasse. There were also a few levee slides which occurred during the flood.

b. Vicksburg District

i. SYSTEM #5901 – West Bank Mississippi River Levee. Five areas of uncontrolled seepage and sand boils were recorded that were defined as impacting the ability of the System to perform; however, these damages did not cause the System to breach. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #5901 is unacceptable.

Prior to the flood, this system was also rated as unacceptable.

System Performance during the 2011 event revealed deficiencies in seepage and sand boil conditions. The most significant issues observed were at Lake Bruin, Leland Chute, Lake Chicot, Henderson, and Ice Box Hole. Lake Bruin has had problems with sand boils during past high water events. During the 2011 Flood, seven boils with cone diameters varying from 2 to 5 feet were located approximately 250 feet from the levee toe (photograph VI-5). The Leland Chute site developed moderate seepage exiting at the toe of the levee and numerous small to medium boils in a ditch 100 feet from the levee toe (photograph VI-6). The Lake Chicot site has historically been an area with large boils and has moved significant quantities of material during high water events (photograph VI-7).

Photograph VI-5. Lake Bruin

Photograph VI-6. Leland Chute

Photograph VI-7. Lake Chicot

At Henderson, numerous boils were located in a ditch running parallel to the levee toe (photograph VI-8). The ditch is approximately 20 feet from the levee toe and required sand bag dams to increase head pressure to slow the boils. The Ice Box Hole is historically an active area during high water events (photograph VI-9). Multiple boils from pin size to large boils were located between 75 and 250 feet from the existing seepage berm.

Photograph VI-8. Ice Box Hole

Photograph VI-9. Henderson

ii. SYSTEM #5921 – East Bank Mississippi River Levee. Six areas of uncontrolled seepage and sand boils and one levee slide were recorded that were defined as impacting the ability of the System to perform. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #5921 is unacceptable. Prior to the flood, this system was also rated as unacceptable

System Performance during the 2011 event revealed deficiencies in seepage and sand boil conditions and levee slope stability. The most significant issues observed were at Buck Chute, Albemarle, Francis, Winterville, Rena Lara and Tara. Buck Chute has had problems with sand boils during past high water events, but the 2011 event significantly worsened the boils. During the 2011 Flood, an emergency berm was constructed over the area which encompassed the worst known boil areas (photograph VI-10). As the flood waters rose, a decision was made to flood the entire project site to prevent failure of the levee at this site. The Albemarle site developed 5 medium sized, high energy sand boils and two significant landside slides immediately downstream of the boils (photograph VI-11). Limestone was placed at the toe of the levee and backfilled with sand and the sand backfill was topped with limestone.

Photograph VI-10. Buck Chute

Photograph VI-11. Albemarle Levee Slide

At Francis, one large high energy sand boil was located at the toe of a 200-foot seepage berm. Two additional sand boils of moderate energy were located approximately 100 to 150 feet from the berm toe (photograph VI-12). At Winterville, one large high energy sand boil was located approximately 30 feet from the toe of a 200-foot seepage berm (photograph VI-13). Four additional sand boils of moderate energy were located approximately 250 feet from the berm toe. Rena Lara was defined as a threat to System performance. The seepage issues consisted of heavy seepage with one large high energy boil, about 40 medium boils, 12 small boils, and hundreds of pin boils (photograph VI-14).

At Tara, moderate heavy under seepage and numerous medium sized sand boils and pin boils were located within 50 feet of the levee toe (photograph VI-15). Additionally, three large high energy sand boils were located between 10 and 20 feet from the levee toe.

Photograph VI-12. Francis Sand Boil

Photograph VI-13. Winterville

Photograph VI-14. Rena Lara

Photograph VI-15. Tara

c. New Orleans District

i. SYSTEM #4401 – Mississippi River East Bank Above Bonnet Carre. Three areas of seepage and sand boils, one levee slope pavement failure, one area of erosion, five areas of cracking and several areas of burrows were recorded that were defined as impacting the ability of the System to perform. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4401 is minimally acceptable. System Performance during the 2011 event revealed deficiencies in seepage conditions, scour, and levee slope stability. For instance, near Duncan Point, a historical sand boil location, a seepage berm was constructed in 2011 (photograph VI-16).

Photograph VI-16. Duncan Point Seepage

ii. SYSTEM # 4405 – St Bernard Polder. Two areas of uncontrolled seepage, one area of possible overtopping, one area of erosion and five areas of damaged slope erosion protection were recorded that were defined as impacting the ability of the System to perform. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4405 is minimally acceptable.

System Performance during the 2011 event revealed deficiencies in seepage conditions, damaged levee slope armoring, deficient gate structure height, and embankment toe erosion. During the event there were nine Hot Spots along the MR&T St. Bernard Polder. The two unacceptable assessed locations are the Chalmette Seepage and the Jackson Barracks Concrete Slope Paving (CSP) damage (photographs VI-17 and VI-18). These are known sites before the 2011 Flood event. The Jackson Barracks CSP damage involves the New Orleans Sewer and Water Board discharge pipe. The slope paving has cracked beneath the discharge pipe supports that connect below the water line. The damaged bottom slope panels allowed erosion of the levee embankment slope material and the undermining of discharge foundation.

Photograph VI-17. Chalmette Seepage

Photograph VI-18. Jackson Barracks Cracked Slope Paving

iii. SYSTEM #4410 - Belle Chasse. Cracked concrete slope paving was observed at West Plaquemines Levee District station 220+00 and was defined as impacting the ability of the System to perform (photograph VI-19). Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4410 is acceptable.

System Performance during the 2011 event revealed deficiencies in slope paving with cracks observed at West Plaquemines Levee District station 220+00 (Belle Chasse Slope Paving).

Photograph VI-19. Cracked Slope Paving at Belle Chasse

iv. SYSTEM #4415 – Mississippi River Westbank – Above Old River. There was one reported area of sand boils, one old levee slide which occurred prior to this event, and two areas of erosion, which were reported as impacting the future ability of the System to perform if not repaired (photograph VI-20). Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4415 is minimally acceptable.

Photograph VI-20. Old River Seepage

System Performance during the 2011 event revealed deficiencies in seepage/sand boils, levee slope stability, and levee height. The area of most concern is the seepage area downstream of Old River Lock. Prior to the area being flooded by backwater from the Old River outfalls, there were three sand boils that required sand bag rings and numerous small sand boils that were flowing clear water. Once the backwater built up, the sand boils stopped flowing. The System was not impacted by the 2011 Flood; however, delays in implementing remedial action will only enhance the problem.

The next area of concern is the old slide on the floodside slope of the levee upstream of the S.A. Murray Hydropower plant (Blackhawk Slide). Prior to the river reaching bankfull stages, the Memphis District hired labor unit “dressed” out the slide to provide a uniform smooth slope and seeded the repaired slope (photograph VI-21). The proposed rock berm was never constructed due to logistical problems of getting riprap to the slide site. There was insufficient room on the batture to transport and place the riprap by barge and since the riprap berm had to be placed from the bottom to the top a decision was made to monitor the area during and after the flood event. There were no impacts to the levee during the 2011 Flood.

Photograph VI-21. Scouring Across From Blackhawk

v. SYSTEM #4425 – Mississippi River West Bank – Below Morganza. One area of controlled seepage and sand boil were recorded that were defined as impacting the ability of the System to perform. No breach occurred with this System as a result of these damages. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4425 is minimally acceptable. System Performance during the 2011 event revealed the following deficiencies in seepage conditions and levee slope stability:

- **MVN-MT-0005—Slope Stability.** E-50-52 floodwall tracked by ED for stability concerns (photograph VI-22).
- **MVN-ML-0006—Sand Boils (Audubon Seepage).** Sand boils occurred at levee toe as well as through seepage creating soft, spongy slopes (photograph VI-23).
- **MVN-ML-0007—Seepage (Point Coupee).** The seepage is on the levee slope only (photograph VI-24).
- **MVN-ML-0008—Seepage (Point Pleasant).** Sand boil is present at the levee toe (photograph VI-25). Blanket has been fractured.

Photograph VI-22. E-52 Floodwall Section

Photograph VI-23. Audubon Seepage

Photograph VI-24. Point Coupee Seepage

Photograph VI-25. Point Pleasant Seepage

vi. SYSTEM #4452 – Westwego-Harvey-Algiers Polders. Three areas of seepage, four areas of scouring, two areas of sediment, and a slope stability issue at Algiers Point (RM 94.485) were recorded that were defined as impacting the ability of the System to perform. No breaches occurred with this System as a result of reported damages. Considering the observed performance of the levee System and damages that resulted from the event, the overall rating for the post-flood System #4452 is minimally acceptable. System Performance during the 2011 event revealed deficiencies in seepage conditions, levee slope stability, and the deficient wall height at the Harvey Lock Structure.

4. Floodways

a. Bird's Point-New Madrid Floodway. During the Flood of 2011, the BPNM Floodway was operated to divert peak river flows to relieve stress on other parts of the MR&T System (photographs VI-26 and VI-27).

Photograph VI-26. Operation of Lower Inflow Crevasse

Photograph VI-27. Arial View of Upper Inflow Crevasse After Activation

Damage assessment began immediately upon operation of the Floodway. The floodway functioned successfully, but damages resulted from artificially crevassing of the levee at 3 locations, and included damages related to the activation, erosion damage to the levees and inside the floodway, and sediment deposition within the floodway. Flood flows through the floodway caused extensive damage to roads, bridges, utilities and other public and private infrastructure. Photographs VI-28 through VI-31 illustrate the types of damage that occurred within the floodway. Damage to the levee system was described in the previous section.

Photograph VI-28. Washed Out Bridge

Photograph VI-29. Damaged Bridge

Photograph VI-30. Washed Out Road

Photograph VI-31. Typical Erosion Near Road

b. Morganza Floodway. During the Flood of 2011, the Morganza Control Structure (MCS) was operated to divert a peak flow of 186,000 cfs (out of a 600,000 cfs design capacity). While this operation was successful, significant downstream scour occurred immediately beyond the derrick stone apron at the end of the stilling basin in the tailbay (photographs VI-32 through VI-34). The scour occurred downstream of the structure. The low tailwater associated with the small number of gates open was likely a significant factor in the scour of the exit channel. If left unchecked, this scour could have approached the structure and threatened its integrity. A similar scour occurred during the 1973 operation of the floodway and, prior to 2011, it was believed that the derrick stone apron repairs and addition of a concrete plunge pool performed in 1977 would suffice for future operations. However, the scour reoccurred in 2011.

Photograph VI-32. Scour Holes in the Morganza Tailbay After the 2011 Flood (displaced riprap visible in upper right)

Photograph VI-33. Damage to Morganza Tailbay Showing Scour Holes and Displaced Stone

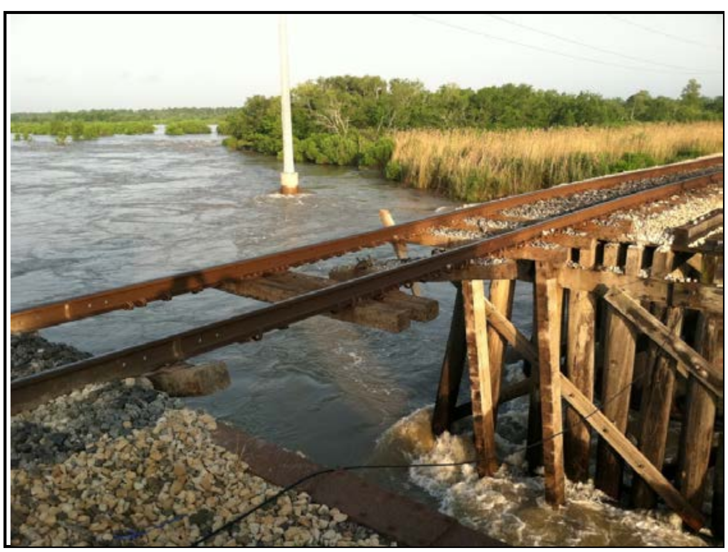
Photograph VI-34. Damage to Morganza Tailbay Showing Scour Hole and Displaced Stone After Dewatering

Damage assessment began immediately upon operation of the Floodway, with monitoring of scour indicator buoys anchored in the tailbay. When some of these buoys were dislodged, multibeam surveying of the tailbay was performed, with gate openings at the structure adjusted as needed to allow the survey boat to access the scoured areas. Six multi-beam surveys were performed during the 2011 operation. These were used to rapidly create maps of scour depths (example map included in Appendix C, *Floodways and Backwaters*), and as additional scour data was collected, the maps were compared to illustrate patterns of progressive scour damage. Scour also occurred along the south forebay guide levee due to wind driven wave wash in the forebay. This scour was monitored daily while sandbags were placed on this levee to prevent overtopping.

The New Orleans District has contracted ERDC to develop a physical model to assist in determining an appropriate method for repairing the damage that occurred to the tailbay. The physical model will also be able to assist in the process of deciding solutions avoid this type of damage in the future. To develop the physical model, ERDC will review existing project information related to operation and scour that occurred as a result of the 1973 and 2011 floods. These will include headwater, tailwater, and sequence of gate opening and closing. Identify headwater and tailwater conditions that led to adverse stilling basin performance. Adverse conditions that could lead to excessive scour could be spray off the baffle blocks and sweep out of the jump from the stilling basin.

These repair and recovery efforts will work to repair the damages incurred by the 2011 Flood, but modeling alone will not determine a long-term solution to a potential problem that has developed over the last 40 years.

c. Bonnet Carré Spillway. The Bonnet Carré Spillway did not sustain any significant damages during the Flood. A water level gage at downstream end of the Spillway near Lake Pontchartrain was destroyed and washed away on May 11. Significant sedimentation occurred both in the forebay and in the Spillway itself, but this had no significant impact on Spillway channel capacity and will eventually be removed by sand hauling companies. As expected, St. Charles Hwy 12 through the Spillway was washed out and had to be replaced after the flood. In addition, a section of the Canadian National railway trestle through the Spillway was damaged (photograph VI-35). This damage was first noticed on the afternoon of Sunday, May 22. It likely occurred that day. The trestle was repaired by Canadian National on May 27, and rail service resumed that afternoon.



Photograph VI-35. Damage to Canadian National Railway Trestle

d. West Atchafalaya Floodway. The West Atchafalaya Floodway was not operated during the 2011 Flood nor did it sustain any damages during the Flood.

e. Old River Control Complex. The ORCC sustained damages in the form of wave wash erosion along the north and south banks of the Low Sill Structure outflow channel behind the wing walls and sedimentation in the inflow and outflow channels (figure VI-5).

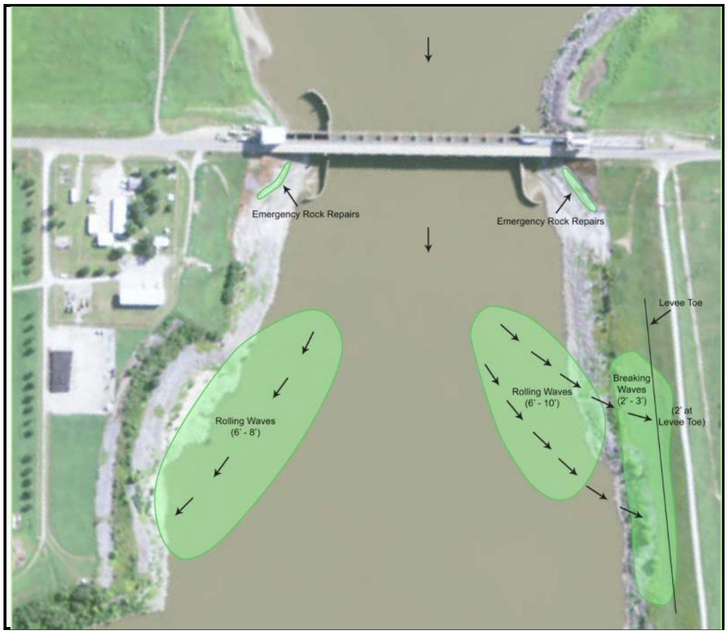


Figure VI-5. Location of Wave-Wash Erosion and Repair in the Outflow Channel of the Low Sill Structure

Low Sill outflow channel erosion was monitored and emergency repairs performed on May 13 and 14 by placement of rock to protect the banks. Sedimentation in the structure channels, particularly in the Auxiliary Inflow Channel, caused erosion along the channel banks but did not require immediate repair (photograph VI-36). This erosion was monitored from the guide levees to ensure it did not require emergency measures.

Photograph VI-36. Sediment in the Inflow Channel of the Auxiliary Structure Sandbar Extends Approximately Halfway Across the Channel

5. Backwater Areas. Because they were not operated during the 2011 Flood, the St. Francis River, White River, Yazoo, River, and Red River Backwater Areas did not sustain any flood-related damages.

6. Interior Drainage Systems. Rain events during the flood impacted interior drainage during the flood event. As noted in subsequent discussions, some interior drainage structures were not operable as a result of higher stages on the flood side versus the land side. Some areas would have experienced flooding from interior drainage issues had it not been for drought conditions.

a. St. John's Bayou - New Madrid Floodway. Within the Floodway, there was damage to homes, businesses, roads, bridges, utilities and farmland. Interstate 55 had one lane closure in each direction. These impacts and damages are primarily attributed to operation of the Bird Point's New Madrid Floodway and not specifically to interior drainage issues. However it should be noted that this area was experiencing some interior drainage flooding due to heavy rainfall prior to the operation of the floodway.

b. St. Francis River Basin. The pump stations were operated for longer than normal. However, there were no major damages reported. There was more than usual wear and tear but the system operated as designed. Funding is in place to repair the pump stations as part of scheduled operation and maintenance.

c. Yazoo River Area. No damages in the Yazoo River area occurred during the 2011 Flood. The system operated as intended. No deficiencies were reported and no immediate repairs are needed.

d. Lake Chicot Pumping Plant. No damages occurred at the Lake Chicot Pumping Plant during the 2011 Flood. The system operated as intended and no deficiencies were reported.

e. Upper Point Coupee Parish Loop. No damages occurred in the Upper Point Coupee Parish Loop area during the 2011 Flood. There was minor leakage through the gate seals of the PCDS, but not significant enough to cause meaningful negative impacts.

f. Bayou Courtableu Drainage Structure and Darbonne Drainage Structure, No damages occurred at the either the Bayou Courtableu Drainage Structure or the Darbonne Drainage Structure during the 2011 Flood. If a rain event had occurred, no water could have been diverted into the Floodway because flood-side stages at the structures were higher than the land side stages.

g. Hanson Canal. No damages occurred in the Hanson Canal area during the 2011 Flood. Portions of the emergency measures were removed to allow the canal to function for its intended purpose. A Corps permit allowed the remainder of the sponsor constructed emergency measure to be left in place for future use during emergency events. If a rain event had occurred during the flood, the canal could not have properly drained due to the sheet pile closures. If the Canal is left open during a flood event, there is a risk that backwater effects east of Wax Lake Outlet could raise the water levels in the canal and the surrounding communities could experience flooding.

h. Franklin Canal. . No damages occurred in the Franklin Canal area during the 2011 Flood. Portions of the emergency measures were removed to allow the canal to function for its intended purpose. A Corps permit allowed the remainder of the sponsor constructed emergency measure to be left in place for future use during emergency events. If a rain event had occurred during the flood, the canal could not have properly drained due to the sheet pile closure. If a rain event occurs during another flood while the Canal is closed, there is a risk of flooding due to inadequate drainage. If the Canal is left open, there is a risk that backwater effects east of Wax Lake Outlet could raise the water levels in the canal and the surrounding communities could experience flooding.

i. Yellow Bayou. No damages occurred in the Yellow Bayou area during the 2011 Flood. Portions of the emergency measures were removed to allow the bayou to function for its intended purpose. A Corps permit allowed the remainder of the sponsor constructed emergency measure to be left in place for future use during emergency events. If a rain event had occurred during the Flood, the canal could not have been properly drained due to the sheet pile closure. If a rain event occurs during another flood while the canal is closed, there is a risk of flooding due to inadequate drainage. If the Bayou is left open, there is a risk that backwater effects east of Wax Lake Outlet could raise the water levels in the canal and the surrounding communities could experience flooding.

j. Bayou Chene. On May 18, 2011, during placement of the sheet pile, increased water flow and hydraulic forces caused a toe failure of approximately eight pairs of sheet pile. The failure left an 85-foot opening near the center of the barge and caused the channel bottom to scour to approximately -67.0-foot elevation (NAVD88). If a rain event had occurred during that time, rainfall in Amelia or the surrounding area normally drained through Bayou Chene could potentially be drained through the eastern portion of the GIWW, although some level of pumping would be required to drain rainfall from the area with the closure in place. Due to the velocity of the water entering the failure area and the depth of the scour, the failure gap had to be repaired using large stone. On 20 May, the Corps supplied SMLD with five barges of 600 stone to be placed in the failure gap. Construction was completed May 25, 2011 and no other damages occurred. As seen from the flood event of 1973 and again in 2011, Bayou Chene is susceptible to major increases in water levels from flood water in the Atchafalaya Basin, exposing a large area east of the Atchafalaya Basin to backwater flooding.

7. Flood Damage to Channel Improvement Features. A post-flood inspection and survey program was conducted to scope the damages to channel structures. Unlike many other components of the MR&T system, the channel structures damages are first revealed only after the waters recede exposing some dikes and eroded bank lines. Many issues and their full extent can only be determined by underwater surveys. The scope, consequences, repairs and their preliminary costs are documented in three Damage Assessment Reports (DAR). The DARs contained information to support subsequent prioritization and ranking of all damages to the MR&T System. In total, a significant number of channel structure sites sustained damage to articulated concrete mattress (ACM) revetment and dikes during the 2011 Flood. If not repaired, 44 sites could impact future system performance. Damage to channel improvement features were categorized as either critical or non-critical as part of prioritization of all the damages to the system. The following paragraphs summarize damages to the channel and the structures protecting it.

a. Critical Sites. Critical sites are primarily those revetments that are located in close proximity to the mainline Mississippi River Levee. Revetment failure at these locations could compromise the integrity of the mainline levee. Two critical sites not located in close proximity to a mainline levee are Merriwether-Cherokee and President's Island in the MVM reach of the river. At these sites, the river scoured the overbank to the degree that channel relocation would have occurred had the flood been of sufficient duration. If these relocations had occurred, the impacts to the channel upstream and nearby levee would have been devastating.

Damages to revetments include upper bank erosion, toe scour, and areas of revetment failure. Primary damage to dikes includes flanking, blowouts, expansion of existing notches, downstream scour pockets in the bankline, and overall structure degradation. If left unrepaired, this damage will grow over time presenting a bigger threat to the integrity of the flood risk management and navigation systems and increasing the cost of repairs. Typical revetment and dike damage is shown in photographs VI-37 and VI-38.

Photograph VI-37. Typical Revetment Damage

Photograph VI-38. Typical Dike Damage

Table VI-3 lists the damaged sites identified as having an impact on system performance.

TableVI-3. Damaged Channel Sites Impacting System Performance

District	Item	Estimated Cost ($1000)	Squares[1]
MVM	Cache-Cairo	$26,110	45,000
MVN	Third District	$11,400	Stone
MVM	Chute of Island 8	$9,650	2,0000
MVM	Merriwether-Cherokee,: top bank and revetment deep		
	Phase 1	$4,600	
	Phase 2	$18,800	
	Phase 3	$6,500	8,100
MVM	Presidents Island		
	Phase 1	$5,300	
	Phase 2	$23,800	
	Phase 3	$5,300	9,600
MVK	Walnut Point/ Kentucky Bend	$13,500	24,800
MVN	Saint Gabriel	$4,040	7,400
MVK	Milliken Bend	$5,460	10,000
MVN	Greenville Bend	$4,350	
MVN	Avondale Bend, RM 108.0	$7,027	
MVN	Avondale Bend, RM 108.3	$5,628	
MVN	Port Allen	$6,307	
MVK	Cypress Bend	$3,276	6,000
MVM	Randolph Dikes	$4,000	Stone
MVM	Walnut Bend	$2,900	5,100
MVM	Oldtown	$6,253	10,500
MVK	Gibson	$1,966	3,600
MVN	Alliance	$6,000	Stone
MVK	Kempe Bend	$14,600	19,835
MVN	English Turn	2566.2	4,700
MVK	Mississippi River Repairs btn 610-320 AHP	$10,032	
MVM	Mississippi River Repairs btn 956-599 AHP	$8,003	
MVN	Mississippi River Repairs btn 320-0 AHP	$3,014	
MVM	Merriwether-Cherokee, US DS Revetment	$8,212	10,500
MVM	Fritz	$5,822	9,000
MVM	Commerce***	$6,000	15,000
MVK	Dennis	$4,805	8,800
MVK	Bourgere	$23,587	43,100
MVM	Little Cypress	$6,386	9,800
MVM	Mhoon Bend	$2,184	18,000
MVK	Goodrich Upstream Extension	$3,413	Stone
MVM	Ensley	$13,631	3,600
MVM	Below Richardson Landing	$6,500	
MVN	Saint Alice	$2,839	5,200
MVN	Tropical Bend	$3,112	5,700
MVN	Port Sulphur	$1,419	2,600
MVN	Gravolet	$3,003	5,500
MVK	Morville	$3,276	6,000
MVK	Hardscrabble DS Ext	$2,184	4,000
MVK	Mayersville	$1,770	3,200
MVK	Big Island	$1,200	Stone
MVM	Rescue	$9,300	1,6500
MVN	Marchand	$3,711	11,200
MVK	Leland - Lagrange	$1,138	Stone

[1] a section of articulated concrete mattress that measures 4 feet by 25 feet

A map indicating location of the critical repair items can be found at the end of this report in Plate 4. A brief discussion of the most significant of the sites to sustain critical damage is as follows:

i. Memphis District

Cache-Cairo Revetment is located on the Right Descending Bank (RDB) of the Ohio River, RM 978 to 976. Approximately 8 feet of scour occurred at the revetment toe and in the bank over a length of approximately 2,300 feet. Additionally, there is approximately 5,300 feet of over-steepened bank in this vicinity. There are several areas of Articulated Concrete Mattress (ACM) that are most likely damaged or destroyed. Threatened infrastructure includes an MRL floodwall less than 100 feet from top bank, the City of Cairo's water treatment plant, a railroad and the Cairo-Ohio River Bridge. Figure VI-6 shows the location of this damage. Figure VI-7 is a sample cross section of the Ohio River showing the depth and a portion of the proposed repair.

Figure VI-6. Location of Damage to Cache-Cairo Revetment

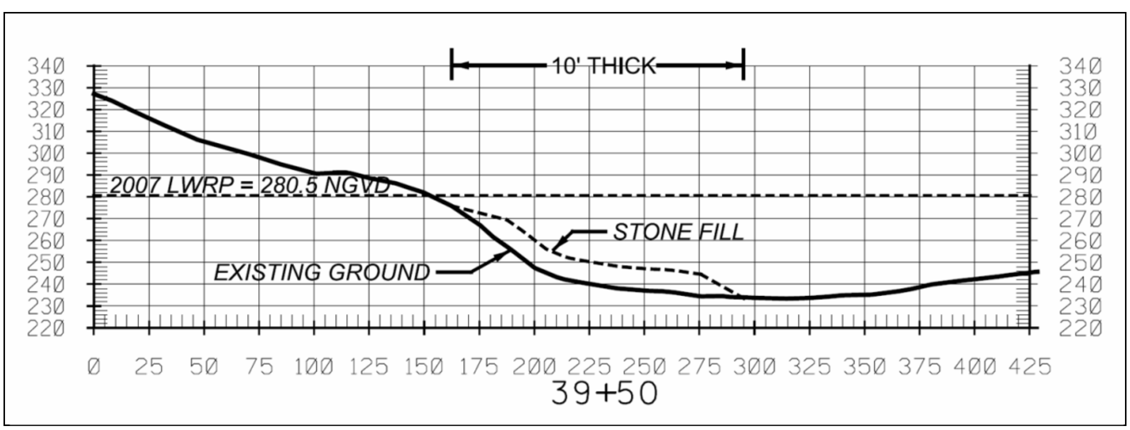


Figure VI-7. Cross Section of Proposed Repair at Cache-Cairo on the Ohio River

Chute of Island 8 Revetment is located on the Left Descending Bank (LDB) at RM 911. The revetment is located within 500 feet of a mainline levee. The revetment experienced damage from a number of sources during the flood (photographs VI-39 and VI-40). Top bank scour occurred for a distance of approximately 2,500 feet along the tree screen at depths up to 4 feet resulting in damage to trees including root exposure and trees falling over. A scour hole with dimensions of approximately 200 ft wide x 100 ft long x 25 ft deep occurred at top bank near the bend in the bank line, and ACM anchors were pulled from the bank. Hydrographic surveys indicate multiple failures occurred at a number of reaches with steepening slopes on the order of approximately 1V on 2H. This revetment experienced prop wash damage from northbound navigation traffic, as well as damage from river currents. The mainline levee in the vicinity of this revetment was a critical concern during the flood due to the existence of numerous sand boils and pin boils at the landside toe.

Photograph VI-39. Scouring at Island 8

Photograph VI-40. Aerial View of Damage at Island 8

Merriwether-Cherokee Revetment is located on the LDB at RM 869. A private levee, Sheep's Ridge Levee, is located adjacent and approximately parallel to top bank. The flood eroded away approximately 2,700 feet of top bank including the levee. During the event, the surrounding cropland eroded inland for a distance of approximately 2 miles. Erosion also occurred toward the river scouring the bank until failure of the revetment occurred. The scour hole extends 3,000 to 4,000 feet inland and is up to 2,700 feet wide and 80 feet deep in some areas. The volume of material eroded away is estimated to be between 6 and 8 million cubic yards. Photograph VI-41 shows flood flows moving through the private levee and across the overbank area. Figure VI-8 shows the location after the flood had receded considerably.

Photograph VI-41. Flood Waters Flowing Through Sheep's Ridge Levee

Figure VI-8. Private Levee After Flood Waters Have Receded

Figure VI-9 shows the entire Merriwether-Cherokee bendway with flow path indicated and the magnitude of the potential cutoff.

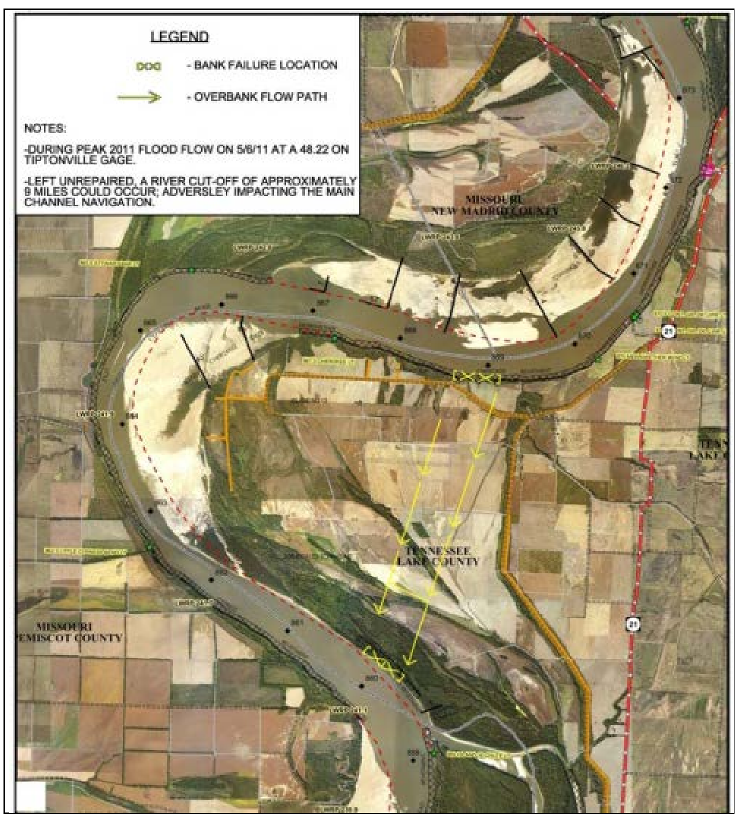


Figure VI-9. Merriwether-Cherokee Failure/Overbank Scour

President's Island Revetment is located on the LDB at RM 732. The flood eroded away approximately 3,200 feet of top bank. The resulting scour hole extends 2,000 feet inland and is approximately 1,000 feet wide and is about 80 feet deep in some areas. Figure VI-10 shows the path of the overbank flow. Photograph VI-42 shows President's Island during the Flood.

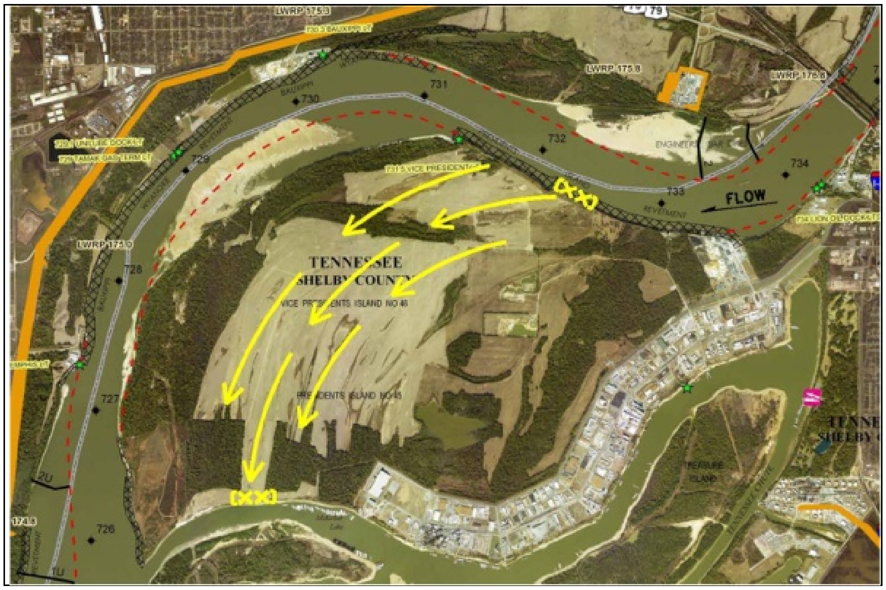


Figure VI-10. Path of Overbank Flow at President's Island

Photograph VI-42. President's Island During 2011 Flood

Below Richardson Landing is located on the LDB at RM 768, approximately one mile downstream of the Richardson Landing Mat Casting Field and 500 feet downstream of the Richardson Landing boat ramp. No bank protection existed in this area prior to the 2011 Flood. During the flood, a top bank failure and overbank failure occurred along a 1,700-foot reach of top bank. The failure at top bank is approximately 30 to 35 feet deep from the surrounding bank elevations. The overbank scour runs inland approximately 1,000 feet and is up to 35 feet deep in places.

Randolph Dikes are located at approximate RM 770 on the LDB. During the flood, the dikes, trail dike and tiebacks were damaged.

Ensley Revetment is located on the LDB at RM 724 and about 1.5 miles south of McKellar Lake. During the flood, a 1,000-foot portion of top bank scoured away with depths of 40 to 45 feet. The land behind top bank eroded inland for a distance of approximately 1,000 feet.

Walnut Bend Revetment is located at approximate RM 679.5 on the RDB. The flood damaged approximately 1,700 feet of ACM revetment within about 1,500-2,000 feet of the levee.

Oldtown Revetment is located at approximate RM 643 on the RDB. The flood scoured the bank and toe and damaged about 2,500 feet of ACM revetment.

ii. Vicksburg District

Delta Mat Casting Field, located at approximate RM 438, experienced various sized scour holes, sediment deposition adjacent to and between rows of mat, damaged forms, and water damage to the field office and laboratory (photographsVI-43 through VI-46). Some mat was damaged when undermined by the scour holes and others were rolled up by the force of the flowing water. At the time of the flood, ACM was being cast. The repairs were critical so that the contractor could resume casting as soon as possible.

Photograph VI-43. Damage at Casting Field

Photograph VI-44. Damage at Casting Field

Photograph VI-45. Damage at Casting Field

Photograph VI-46. Damage at Casting Field

Walnut Point/Kentucky Bend, located at RM 517.3 on the LDB, experienced greater than 20 feet of bank caving and greater than 20 feet of scour at the toe of the revetment for approximately 6,200 feet. The revetment is approximately 850 feet from the toe of the levee. Continued scour and erosion that damages the revetment will threaten the integrity of the levee and will have an impact to the channel alignment. Figure VI-11 shows the location of the damage and the damages themselves are shown in photograph VI-47.

Figure VI-11. Location of Walnut Point/Kentucky Bend

Photograph VI-47 Damage at Walnut Point/Kentucky Bend

Kempe Bend Revetment is located at approximate RM 383.5 on the RDB. The flood scoured depths greater than 25 feet along the toe for about 5,000 feet of ACM revetment. The revetment (photograph VI-48) is approximately 500 feet from the levee toe and 150 feet from the closest part of the existing borrow pit. Loss of the revetment and supporting land mass would expose the levee toe to the erosive forces of the river.

Photograph VI-48. Borrow Pit in Relation to Kempe Bend Revetment

Leland-LaGrange Revetment is located at approximate RM 537.5 on the LDB immediately upstream from the entrance to the Greenville, MS harbor. The flood scoured 20 feet at the toe along 6000 feet of ACM and scoured the strip of land separating the Greenville Harbor entrance from the river channel. At higher flows, this scour diverts a portion of the flow from the main channel into the harbor entrance creating undesirable flow patterns in the harbor as shown in photograph VI-49.

Photograph VI-49. Flood Damage at Leland-LaGrange Revetment Near the Entrance to Greenville Harbor

Dennis Revetment is located at approximate RM 611.3 on the LDB. During the flood, scour of greater than 20 feet occurred at the revetment toe. This scour extends along the toe for approximately 2,200 feet. The toe of the levee is approximately 650 feet from top bank.

Cypress Bend Revetment is located at approximate RM 567.5 on the RDB. The flood scoured in excess of 25 feet at the toe along 1,500 feet of ACM. The revetment is approximately 2,500 feet from the levee toe.

Mayersville Revetment is located at approximate RM 495.0 on the LDB. During the flood, excessive scour occurred along the revetment toe. Upper bank failure also occurred and a section of revetment failed. Damage extended along the revetment for approximately 800 feet. The toe of the levee is approximately 2,500 feet from top bank.

Goodrich Revetment Upstream Extension is located at approximate RM 470.0 in an old bendway on the RDB. This bank is not protected with revetment. Five hard points were constructed along this bank (Cottonwood Hard Points) to maintain the alignment. At least one of the hard points was destroyed prior to the 2011 Flood. During the flood, bank caving and scour occurred along approximately 5,600 feet of this bankline. The levee is approximately 2,100 feet from the existing bankline. Through this bend, several lakes/borrow pits are located along the overbank. The top bank is about 950 feet from the closest lake.

Milliken Bend Revetment is located at approximate RM 453.3 on the RDB. The flood scoured in excess of 20 feet at the toe along 2,500 feet of ACM. Small sections of the revetment have failed. The revetment is approximately 600 feet from the levee toe.

Hardscrabble Revetment Downstream Extension is located at approximate RM 396.2 on the RDB. This bank is not protected with ACM but is located immediately downstream of the existing Hardscrabble Revetment. During the flood, erosion of the bank occurred and a 30-foot deep scour hole developed. The toe of the levee is approximately 2,500 feet from top bank.

Gibson Revetment is located at approximate RM 372.5 on the RDB. The flood scoured the revetment toe for approximately 900 feet. A small section of the revetment has failed. The revetment is approximately 1,200 feet from the levee toe.

Morville Revetment is located at approximate RM 356.3 on the RDB. During the flood, excessive scour occurred along the toe. Upper bank failure also occurred and a section of the revetment failed. Damage extends along the revetment for approximately 1,500 feet. The toe of the levee is approximately 1,250 feet from top bank.

Bougere Revetment is located at approximate RM 329.5 on the RDB. During the flood, scour greater than 20 feet occurred at the revetment toe extending along the toe for approximately 10,770 feet. The toe of the levee is approximately 800 from top bank. Existing borrow pits are located through this bend with the closest one approximately 400 feet from top bank.

iii. New Orleans District

Third District Revetment is located just downstream of the French Quarter in New Orleans at approximate RM 90. The revetment has a length of 2,315 feet. Surveys indicate that 38 feet of scour has occurred since the last revetment was placed in 1959. There is 247 feet of batture separating top bank from the I-wall serving as protection to the downtown area. Studies indicate the bank line has a safety factor of 0.98. A bank failure in this location could jeopardize the integrity of the I-wall and its failure would have severe consequences to the downtown area of New Orleans. Figure VI-12 shows the location of this damage and its proximity to downtown New Orleans.

Figure VI-12. Scour Area near Downtown New Orleans

Figure VI-13 is a cross section of the Mississippi River shows the erosion that has taken place and the relationship of the bank to the Stability Control Line (SCL).

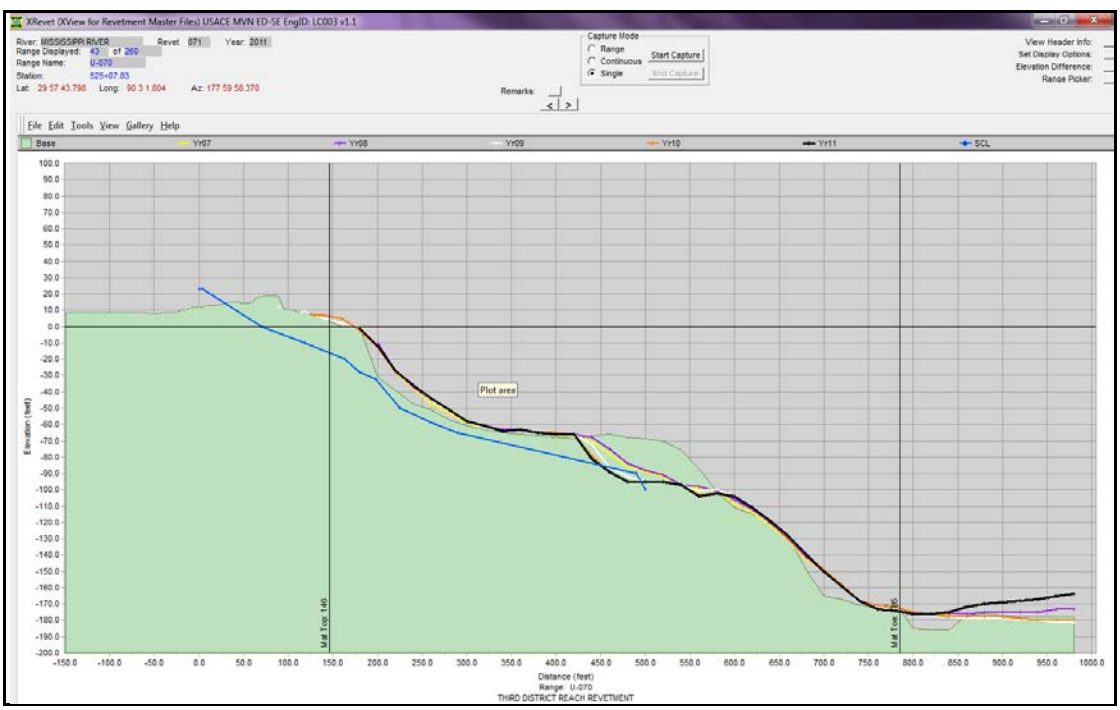


Figure VI-13. Cross Section of the Mississippi River, Showing Erosion and Stability Control Line

Alliance Revetment is located at approximate RM 62.2 on the RDB (figure VI-14). There is an SCL violation at this location: the bank has a safety factor less than unity the levee has a safety factor slightly above unity (figure VI-15). There are 179 feet of batture remaining. This revetment maintains channel stability, which in turn helps maintain the integrity of the levee providing flood risk management to the Conoco-Phillips oil refinery shown in figure VI-14.

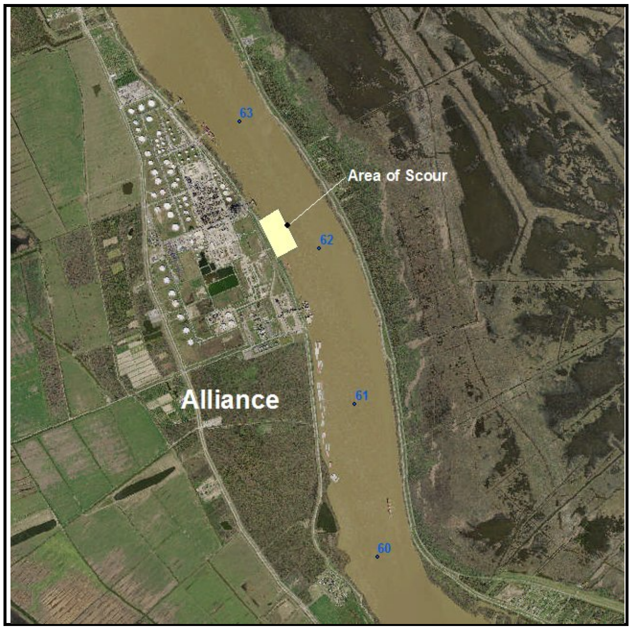


Figure VI-14. Location of Stability Control Line Violation at Alliance

Figure VI-15. Cross Section Showing Stability Control Line Violation

Avondale Bend Revetment is located at approximate RM 108 on the RDB. After the flood, 64 feet of scour was noted which results in an SCL violation and a bank safety factor slightly above unity. There is 179 feet of batture remaining.

Port Allen Revetment is located at approximate RM 231.8 on the RDB. After the flood, 26 feet of scour was noted resulting in an SCL violation. There is 206 feet of batture remaining.

Saint Gabriel Revetment is located at approximate RM 202 on the LDB. After the flood, 23 feet of scour was noted resulting in a bank safety factor slightly above unity. There is 497 feet of batture remaining.

Greenville Bend Revetment is located at approximate RM 98.9 on the RDB. After the flood, 40 feet of scour was noted. This reach of the river is susceptible to flow failure. There is 152 feet of batture remaining.

b. Non-Critical Sites. Appendix D, *Channel Improvements* contains tables listing non-critical items for the Memphis, Vicksburg and New Orleans Districts. The schedule to complete the non-critical projects is dependent on funding and other MR&T priorities. Many will have to compete against other future annual budgets needs of the system. On the other hand, some can be undertaken as opportunities for efficiency present themselves such as reduced mobilization/implementation costs due to being in proximate location of a high priority repair.

Section VI.E of this report further describes the damages to system components and provides additional details related to FRAGO classification.

D. MR&T SYSTEM RECOVERY STRATEGY

A recovery strategy for the MR&T System was developed through an overarching regional effort referred to as Operation Watershed-Recovery (OW-R). This effort had five primary components including:

- DARs
- the MR&T PFR
- Flood Season Preparedness
- Repair/Restore Construction; and
- the IRTF

These components focused on the processes of risk identification, risk reduction and management, and risk communication. Additional details are captured Appendix J, *MR&T System Recovery Strategy*. The MR&T recovery strategy and processes are further explained below.

1. Risk Identification. Multiple efforts were implemented to assess elevated risks in the MR&T System caused by damages from the 2011 Flood. These efforts documented system risks by examining both the probability and consequence of failure for MR&T damaged components (e.g., levees, floodways, reservoirs, etc.). This information was extremely important to identify and appropriately sequence recovery efforts. The risk information was also vital for the Corps and partner agencies to be fully prepared for future flood events that could occur in the damaged system.

a. Damage Assessment Reports and FRAGO 01 Risk Classification. Damage assessment teams began inspecting and monitoring activities during the flood. The teams identified seeps, boils, slides and other anomalies while documenting and uploading information to be used to prepare assessments of the flood related damages. Once the waters receded, these teams continued their assessments and prepared documents which identified the location, nature, extent, economic and life safety consequences, repair alternatives and estimated preliminary repair costs for damaged areas. All MR&T assessments utilized a standard DAR format to keep the data gathering and supporting information consistent. Forty-four separate DARs were developed to ensure that all levee reaches, structures and navigational river miles affected by this event were inspected and thoroughly documented (Appendix B, *Levees and Floodwalls*). The reports were submitted to an oversight team to ensure the consistency, functionality and quality of the final product.

FRAGO 01 risk classifications were utilized to categorize all OW-R repair projects into one of four primary classes. The MR&T System Recovery Appendix (see 2012 Flood Season Preparedness and Emergency Response Summary section) provides further details on the classification system and associated definitions for risk factors of "Failure Likelihood" and "Consequences" established by HQ and applied by MVD. This classification system was utilized to establish the Relative Risk Matrix, shown in figure VI-1. Projects in Classes I, II and IIIa were designated as Critical Repairs, and those in Classes IIIb and IV were designated as Non-Critical Repairs. A Regional Team used this classification process to establish a regional "1-n" prioritization of Critical Repair Projects, referenced as Phase I (Aug 2011) and Phase II (Oct 2011) Critical Repair Prioritizations. Class IIIb and IV items were also reviewed at the regional level and categorized as Phase III (Jan 2012) and Phase IV (Feb 2012) Non-critical Repairs. Based upon the severity of the damages and the guidance provided by the classification guidance, MVD developed a regionally prioritized list of projects (Appendix J, *MR&T System Recovery Strategy* section *2012 Flood Season Preparedness and Emergency Response Summary*). A subset of the Critical Repair projects was designated as "Immediate Need" projects and were self-funded and moved to construction starting in late 2011.

b. Risk Information Papers. In addition to the thousands of pages of DAR information, single sheet project information papers were developed (figure VI-16). These Risk Information Papers were produced to summarize the DAR information and provide a general background on flood damages, potential consequences, repair options and a tentative schedule for repair. These regionally consistent information papers were kept up-to-date by the Districts and publicly served through CorpsMap via the MVD website.

Last Update: 31 August 2011

US Army Corps of Engineers
Vicksburg District

Information Paper
Buck Chute

OPERATION WATERSHED RECOVERY – CRITICAL REPAIR SITES

Contacts
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OVERVIEW
DISTRICT: Vicksburg District
TYPE: Boils and Seepage
RM: RM 459.6 (110+00 BEL)
FRAGO CLASS: 1 – High Potential for Loss of Life
RISK: 3,996 residents, $188.5M infrastructure
REPAIR: Berm, 30 Relief Wells, and 12 Horiz. drains
EST. REPAIR COST: $2,640,000

Damage Assessment
In early 2010, MVK was notified of multiple boils in the project area. In early summer of 2010, the boils were sandbagged as River Levels reached flood stage and the flow of the boils increased. In February, 2011, when conditions in the project area were dry, two of the largest boils were pumped, revealing voids at boil sources as wide as 20 ft and as deep as 10 ft. The voids revealed no obvious "pipes" that continued downward or laterally from the void bottom. As River levels continued to rise and approach flood stages in March 2011, the boil area voids were backfilled with sand material, covered with a nonwoven filter fabric, and either sandbagged or earthen dams were constructed around them. In May 2011, an emergency berm was constructed over the area which encompassed the worst known boil areas. The top of the berm was constructed to approximate elevation 85.0 ft. Because of the high exit gradients for the predicted flood stages for the known boil areas, and the consequences of failure at this location, it was decided to flood the entire project site by raising water levels in Eagle Lake to approximate elevation 90.0 ft through the use of Muddy Bayou Control Structure. In order to reduce the risk of failure without raising water levels in Eagle Lake, remediation is recommended prior to the next high water season.

Risk and Consequence
If the East Bank Mississippi River Levee System were to fail at the Buck Chute site, the population at risk would be 3,996. The value of the non-residential structures is $31,141,000, and the value of the 1,436 residential structures is $157,396,000.

Figure 1. Aerial view of Buck Chute during 2011flood fight.

Critical Repairs
The reset recommendation for this site includes a 1700 ft reach of earthen berm 200 to 240 ft wide and relief wells from Station 106+50 to 123+50. A 400 ft section of the berm includes a drainage and collection feature, including horizontal drains and a pervious sand layer. The item includes 30 relief wells and 12 horizontal drains. In-place berm volumes will be approximately 13,600 cubic yards of sand for the drainage feature and 150,000 cubic yards for the remaining berm.

Special Considerations
The site is covered under the 1998 MRL SEIS, as item 458-L, and covers multiple work items. The SEIS does not cover planned relief wells for this site; however, an EA was prepared to cover these wells and a FONSI signed. Coordination under Section 9 of the Endangered Species Act has been completed. The 404 water quality permit for the project has been obtained, and all project impacts have been mitigated for, as this site is part of the existing MRL mitigation program. This segment of EBMRL is not currently certified, but this fix, along with other work MVK currently has planned in the area, will allow certification of the levee system. The Board of Mississippi Levee Commissioners has acquired the necessary ROW for the project.

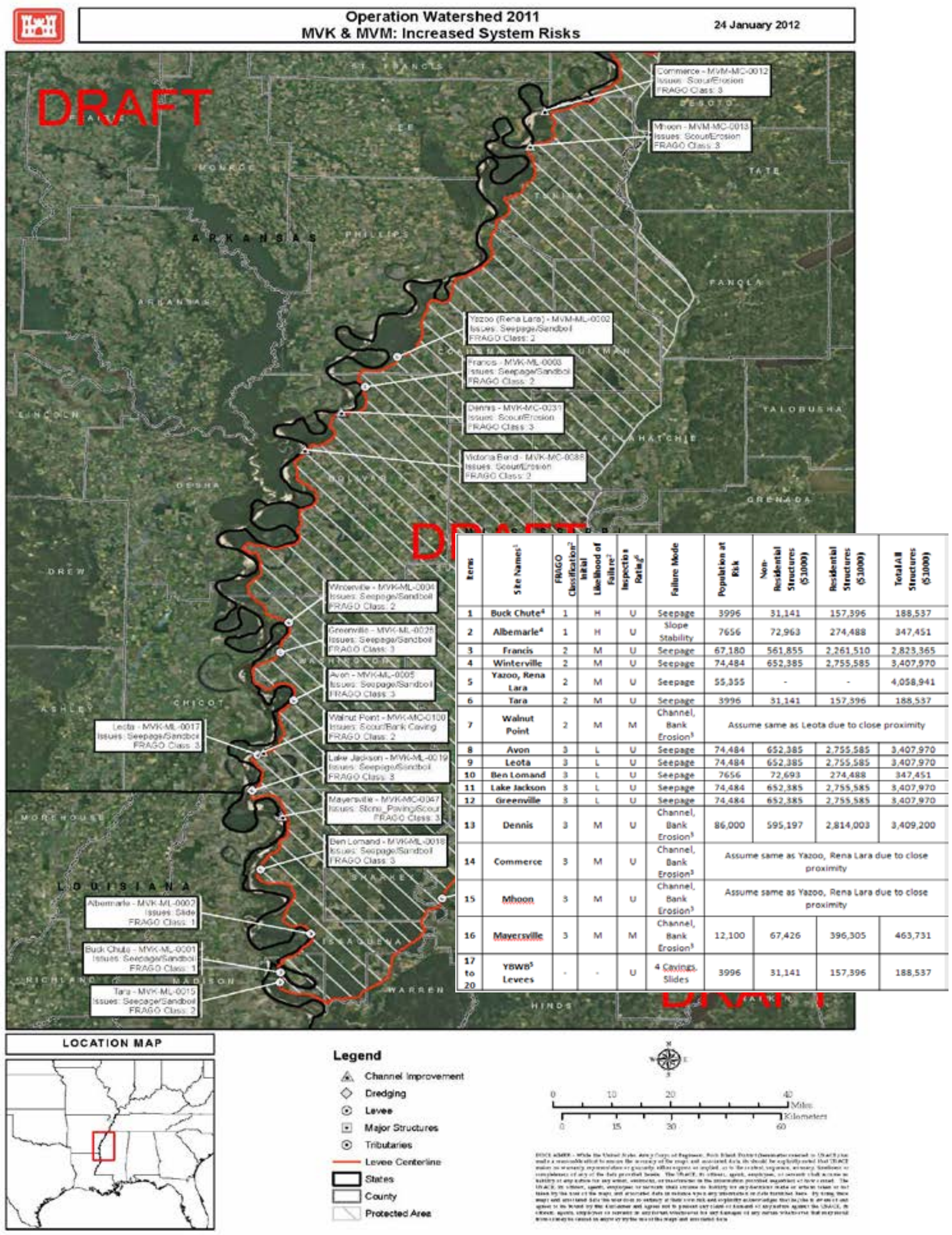
Schedule
Bids solicited - 10 Aug 2011
Contract Awarded - 30 Aug 2011
Anticipated contract duration 120 days. Scheduled completion in January 2012.

Acquisition Strategy
Unrestricted competitive bid awarded 30 Aug 2011 to Phylway Construction, LLC for $3,100,225.00. This site was combined with No. 8 site, Albermarle.

FOUO **PRE-DECISIONAL**

Figure VI-16. Risk Information Paper for Buck Chute

c. Sub-System Risk Documents. Leveed areas are termed "sub-systems" in that together they form the MR&T System. Increased understanding of risk included analyzing all damages to the levee including some channel scour that threatened a leveed area. Sub-System Risk Documents were generated to provide details on elevated risks associated with levee sub-systems (figure VI-17). These three- to four-page standardized documents include a map, table, and text discussing and comparing risks of all damaged locations within the sub-system. The focus of these documents was to further inform the appropriate sequencing of recovery efforts and also clearly indicate to the Corps and partner agency emergency response staff where highest risk (aka, weakest links) may exist within the sub-systems. Residual risks can be understood as construction projects get completed.



Item	Site Name[1]	FRAGO Classification[2]	Initial Likelihood of Failure[2]	Inspection Rating[6]	Failure Mode	Population at Risk	Non-Residential Structures ($1000)	Residential Structures ($1000)	Total All Structures ($1000)
1	Buck Chute[4]	1	H	U	Seepage	3996	31,141	157,396	188,537
2	Albemarle[4]	1	H	U	Slope Stability	7656	72,963	274,488	347,451
3	Francis	2	M	U	Seepage	67,180	561,855	2,261,510	2,823,365
4	Winterville	2	M	U	Seepage	74,484	652,385	2,755,585	3,407,970
5	Yazoo, Rena Lara	2	M	U	Seepage	55,355	-	-	4,058,941
6	Tara	2	M	U	Seepage	3996	31,141	157,396	188,537
7	Walnut Point	2	M	M	Channel, Bank Erosion[3]	Assume same as Leota due to close proximity			
8	Avon	3	L	U	Seepage	74,484	652,385	2,755,585	3,407,970
9	Leota	3	L	U	Seepage	74,484	652,385	2,755,585	3,407,970
10	Ben Lomand	3	L	U	Seepage	7656	72,693	274,488	347,451
11	Lake Jackson	3	L	U	Seepage	74,484	652,385	2,755,585	3,407,970
12	Greenville	3	L	U	Seepage	74,484	652,385	2,755,585	3,407,970
13	Dennis	3	M	U	Channel, Bank Erosion[3]	86,000	595,197	2,814,003	3,409,200
14	Commerce	3	M	U	Channel, Bank Erosion[3]	Assume same as Yazoo, Rena Lara due to close proximity			
15	Mhoon	3	M	U	Channel, Bank Erosion[3]	Assume same as Yazoo, Rena Lara due to close proximity			
16	Mayersville	3	M	M	Channel, Bank Erosion[3]	12,100	67,426	396,305	463,731
17 to 20	YBWB[5] Levees	-	-	U	4 Cavings, Slides	3996	31,141	157,396	188,537

Figure VI-17 Sub-System Risk Document Elements

Sub-System Risk Documents were prepared for the following locations and are provided in Appendix J, *MR&T System Recovery Strategy*. Sub-System documents were only prepared for MR&T locations that experienced three or more significant damage spots in a sub-system because the primary aim of this effort was to help with understanding the risks and inform the process of risk reduction and prioritization of repairs.

Memphis District

1. Mississippi & Ohio River Levee at Cairo and Vicinity
2. Combined Levees from Near Cape Girardeau, MO to Marianna, AR
3. Hickman, KY - Obion Levee
4. BPNM Floodway Levee System

Vicksburg District

5. AR-LA Mississippi River Levee System
6. East Bank Mississippi River Levee and the Yazoo Backwater West Levee

New Orleans District

7. Mississippi River East Bank Levee System
8. St. Bernard Polder Levee System
9. Belle Chasse Polder Levee System
10. Mississippi River West Bank - Above Old River Levee System
11. Wax Lake West Levee System
12. Mississippi River West Bank - Below Morganza Levee System
13. Westwego/Harvey/Algiers Levee System

d. Estimated Level of Protection Map. An MR&T System Level of Protection Map was generated to better understand the overall condition of the system (figure VI-18). Estimates of the levels of protection presented in the map are based on sound engineering judgment and performance of system features during past major floods, primarily the 2011 and 2008 Flood Events. While normal flood fighting measures will be implemented at river stages lower than presented, the level of protection shown on the map indicates the estimated upper limit of river stages that can be safely maintained for a normal duration utilizing ordinary flood fighting measures. For river stages above those presented, it is probable that additional flood fighting measures will be required.

e. Standardized Inundation Mapping and Distribution. Regionally standardized inundation maps displaying potential timing, depth, and consequence of inundation were generated in early 2012 to better prepare for the upcoming flood season (figure VI-19). This figure demonstrates how one weak link in a subsystem elevates risk to the entire leveed area and all that it contains.

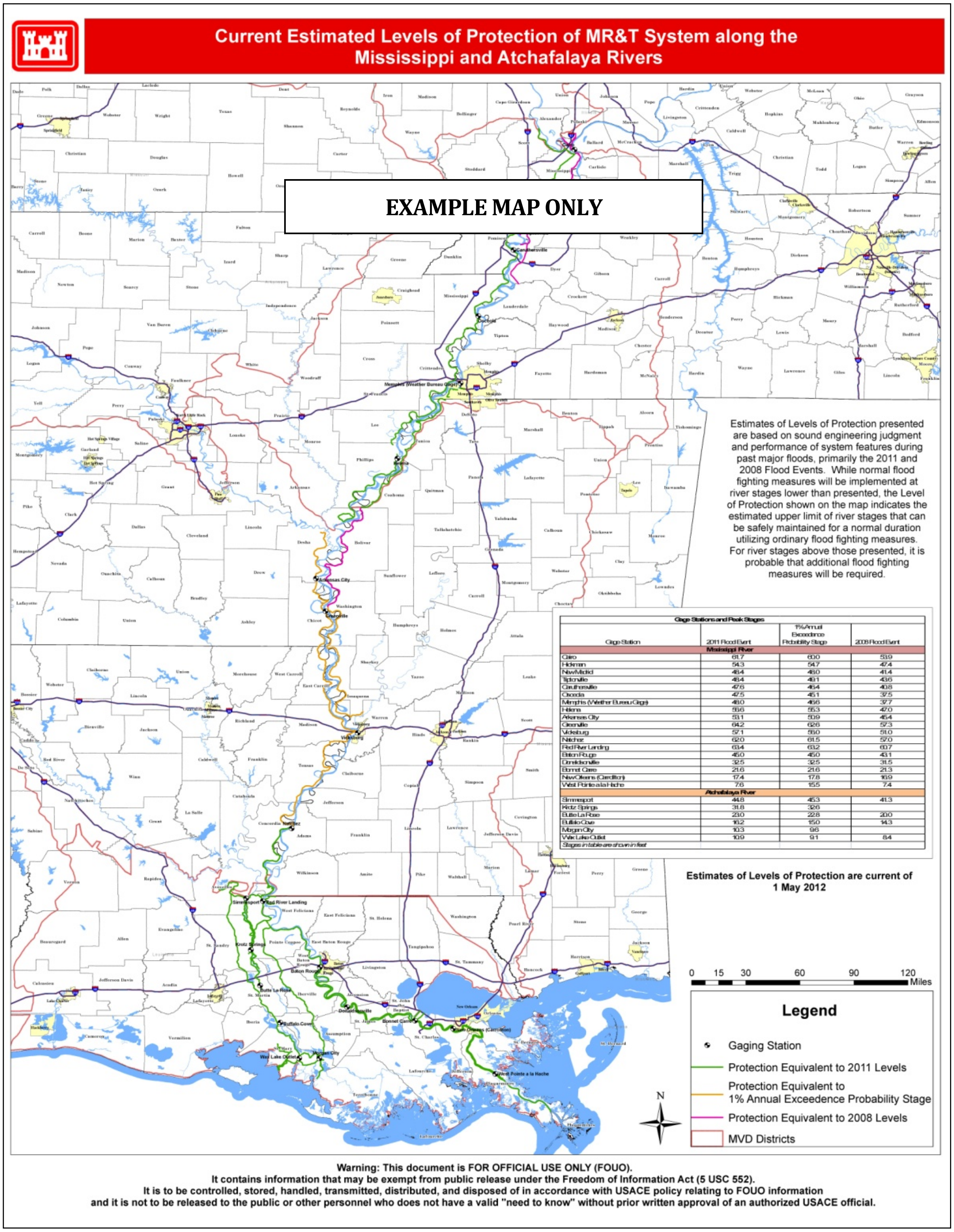


Figure VI-18. MR&T System Level of Protection Map[1]

[1] The map is labeled "For Official Use Only (FOUO)" because of the sensitivity of the information displayed and the need to be sure it is distributed by knowledgeable USACE personnel who can clearly explain how to correctly interpret and use the information.

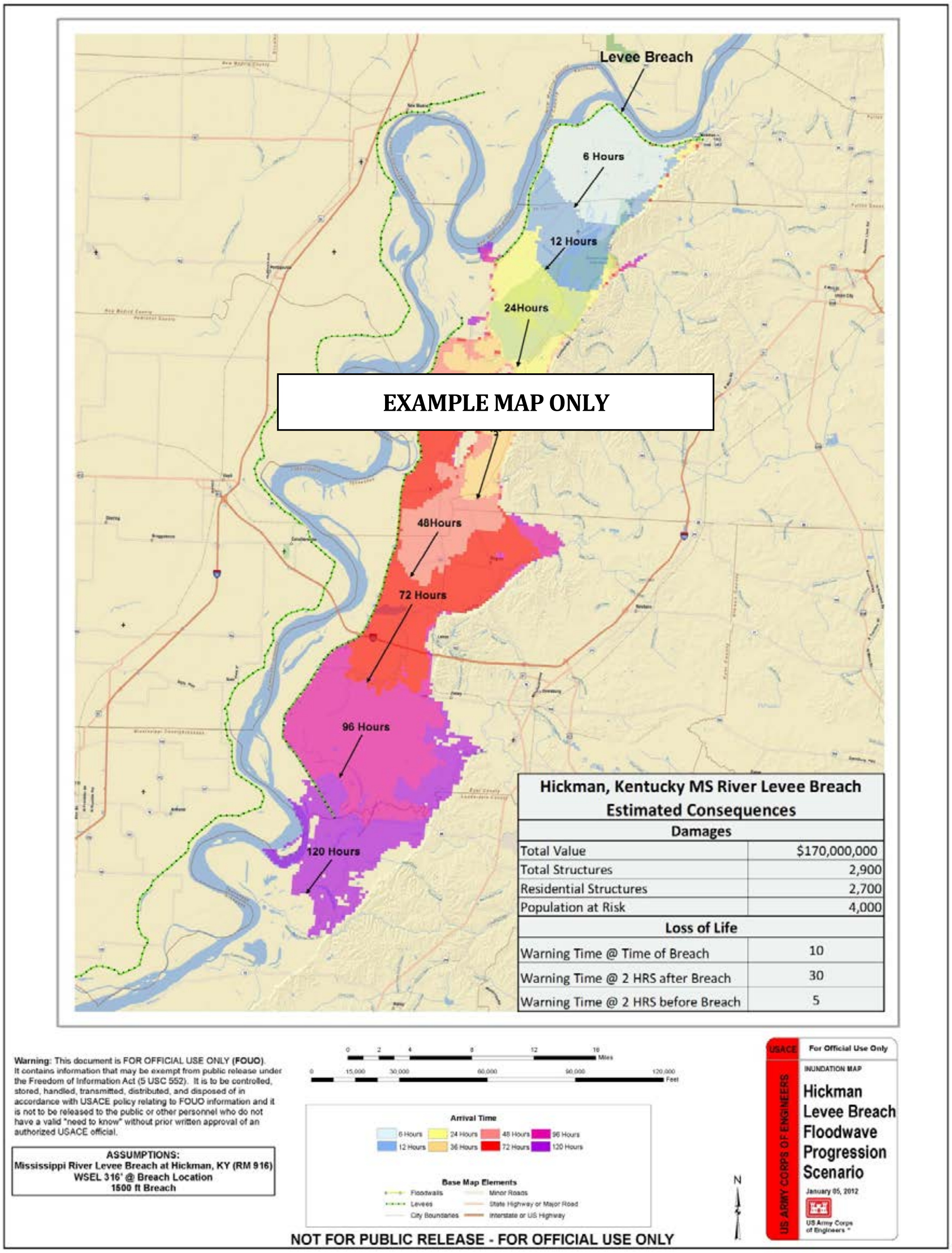


Figure VI-19. Hickman, Kentucky Inundation Map[2]

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[2] The map is labeled "For Official Use Only (FOUO)" because of the sensitivity of the information displayed and the need to be sure it is distributed by knowledgeable USACE personnel who can clearly explain how to correctly interpret and use the information.

These maps covered seven high risk areas in the Mississippi River Valley and one high risk area in the Red River of the North Basin. The mapped locations included:

St. Paul District
1. Souris River (in Red River Basin)

St. Louis District
2. Len Small
3. Cairo

Memphis District
4. Fulton County

Vicksburg District
5. Francis
6. Wilson Point
7. Winterville
8. Tara

A regional Corps team was also poised in early 2012 to quickly prepare these standardized inundation maps as needed for the upcoming flood season. A regionally consistent method of distributing this information to partner Federal and state agencies was also developed and approved by HQ (see approval memo in Appendix J, *MR&T System Recovery Strategy).*

2. Risk Reduction and Management. Reduction and management of elevated risks within the MR&T System proceeded through implementation of recovery construction efforts, interim measures, and flood fight preparation. Communication and coordination of these activities with Federal and state partners was paramount to effectively addressing 2011 MR&T damages and best managing their associated risks.

a. Recovery Construction Efforts. Following the development and validation of information provided in the DARs and FRAGO 01 risk classifications assigned to the damaged MR&T System Components, MVD proceeded with prioritization and implementation of emergency repairs (including non-MR&T damaged flood risk reduction structures). Prior to passage of the Consolidated Appropriations Act 2012, PL 112-74 which provided $1.7 Billion in supplemental funding, the Corps recognized the urgency to self fund 29 “Immediate Need” projects within the valley at cost of $170 million (table VI-4). After passage of the Consolidated Appropriations Act in December 2011, the Corps was able to proceed with implementing 118 “Critical Repair” projects needed to restore and prepare the system for the next high water event. An additional 302 “Non-Critical Repair” projects were also identified and ranked and the supplemental would fund just over 100 of these projects. These recovery projects, located throughout MVD and in each of the Division's six Districts, include Mississippi River levees, channel improvement, dredging projects, and other FRM structures. Appendix J, *MR&T System Recovery Strategy* provides additional details on the MR&T recovery construction strategy and efforts (Appendix J, *MR&T System Recovery Strategy* section *2012 Flood Season Preparedness and Emergency Response Summary*).

b. Construction Fact Sheets. Construction Fact Sheets were developed to provide timely information and updates on USACE risk reduction efforts throughout the MR&T System. These one-page fact sheets presented the status of ongoing construction activities, key milestones, percent completion, project challenges and funding (figure VI-20). Corps Districts maintained these regionally consistent fact sheets, updating them monthly for public distribution through CorpsMap via the MVD website.

TableVI-4. MVD Immediate Needs Recovery Repairs

MVDs OPERATION WATERSHED - RECOVERY
MVD 2011 Critical Flood Repair Projects: Immediate Needs

Feature	Flood Damaged Site	CORPS DISTRICT	STATE	Estimated Cost	FY11-12 Funds Allocated
MRL	BPNM Floodway - Make Safe and Stable	MVM	MO	$25,000,000	$25,000,000
CI	Cache-Cairo	MVM	IL	$26,110,000	$26,110,000
MRL	City of Cairo, IL	MVM	IL	$4,600,000	$4,600,000
MRL	Cairo Parcel 5	MVM	IL	$10,400,000	$10,400,000
MRL	Above Cairo Parcel 2A - Relief Wells	MVM	IL	$6,769,221	$6,769,221
MRL	Above Cairo Parcel 2 - Slurry Trench	MVM	IL	$1,900,514	$1,900,514
MRL	Buck Chute	MVK	MS	$2,640,000	$2,640,000
MRL	Albermarle Slide	MVK	MS	$1,006,000	$1,006,000
MRL	Duncan Point	MVN	LA	$8,850,000	$8,850,000
MRL	Baton Rouge Front	MVN	LA	$1,762,000	$1,762,000
CI	Third District	MVN	LA	$11,400,000	$11,400,000
Struct	Morganza Control, Piezometers and relief wells	MVN	LA	$2,460,000	$2,420,000
CI	Merriwether-Cherokee, top bank and revetment	MVM	TN	$24,115,000	$6,800,000
CI	Presidents Island	MVM	TN	$26,689,000	$7,300,000
PL84-99	Souris River	MVP	ND	$5,000,000	$2,030,000
PL84-99	Scott County Levee Breach	MVS	IL	$1,716,000	$1,716,000
Dredge	Deep Draft Projects - MR Baton Rouge to Gulf	MVN	LA	$10,000,000	$6,000,000
Dredge	Gulf Intracoastal Waterway, LA	MVN	LA	$3,000,000	$3,000,000
FCCE	Tolna Coulee Advance Measures	MVP	ND	$5,680,250	$5,680,250
Dredge	Miss River Btwn Mo River and Minneapolis, MN	MVR	MO/IL/IA/WI	$500,000	$500,000
Dredge	Miss River, Cairo to Mouth of Missouri	MVS	MO / IL	$2,000,000	$2,000,000
CI	Chute of Island 8	MVM	KY	$9,650,000	$600,000
CI	Greenville Bend	MVN	LA	$3,902,000	$5,500,000
CI	Avondale Bend, RM 108.0	MVN	LA	$4,700,000	$4,700,000
CI	Avondale Bend, RM 108.3	MVN	LA	$4,703,000	$4,703,000
CI	Port Allen	MVN	LA	$3,800,000	$3,800,000
CI	Kempe Bend	MVK	LA / MS	$10,920,000	$12,167,000
CI	Bougere	MVK	LA	$23,587,000	$147,800
CI	Richardson Landing Casting Field	MVM	KY	$10,000,000	$1,100,000
			TOTALS	**$252,859,985**	**$170,601,785**

US Army Corps of Engineers

OPERATION WATERSHED UPDATE
Buck Chute - Albemarle (458-L/465-L)
Mississippi

May 01, 2012

Greenwood Project Office — Vicksburg District

Schedule

Actual Contract Award:	Aug. 30, 2011
Actual Notice to Proceed:	Sep. 14, 2011
Orig. required const. completion:	Jan. 12, 2012
Current required const. completion:	*Apr. 20, 2012
Current scheduled const. completion:	*Apr. 20, 2012

*Completion date revised due to weather and river conditions.

Progress

Actual Progress:	88%
Scheduled Progress:	88%
Progress Payments to Date:	$2,972,144.26

Funding

Award Contract:	$3,100,225.00
Modifications:	$15,000.00
Estimated Contract:	$3,115,225.00

Image 1 — Contractor placing berm material at Buck Chute.

Scope of work

The work consists of construction items 458-L and 465-L landside seepage berms and installation of 30 relief wells at Magna Vista and Brunswick, Mississippi. Principle features of the work include, but are not limited to, degrade existing berms, degrade existing stone dikes, stone dike construction, semicompacted and uncompacted berm embankment, relief well construction, horizontal collector drains, excavation, levee surfacing, new turf establishment, erosion control, corrugated metal pipe, storm water pollution prevention, and environmental Protection.

Current Status

All relief wells, horizontal drains, sand fill and earth embankments have been completed at Buck Chute. Some vegetation has come up at Buck Chute in the areas where seeding has been completed. Rainfall and high river stages have contributed to a saturated haul road and borrow area that is preventing further work at the Albemarle site. Buck Chute is essentially complete except for turfing and concrete pads around wells. Wells have already functioned during the recent high water. Contractor is still on site and will haul berm material when conditions are favorable. Both sites are stable and need no contingency plan.

Project Manager: Kent Parrish • Area Engineer: Lamar Jenkins • Project Engineer: Jason Overstreet
Questions? Contact Lamar Jenkins: 662.455.0244 (project office), 662.466.0040 (mobile), or lamar.jenkins@usace.army.mil
The Greenwood Area Office is located at 100 Moore St., Greenwood, MS 38930

Figure VI-20. Construction Fact Sheet for Buck Chute - Albemarle

c. Risk Management Information Papers. Flood Risk Management Information Papers were developed to describe how risks at damaged locations within the MR&T were being addressed through construction, interim measures, and flood fight preparation (figure VI-21). The information papers also identified flood fight activation stages and had a link to the NWS site for current stage forecasts. The documents were formatted to be easy to digest one-page papers describing the status of risk management efforts prior March 2012. The information papers were extremely useful in improving situational awareness of risks within the MR&T System and better preparing the Corps, its partners, and the public for the upcoming 2012 flood season. These regionally consistent documents were developed for 45 high-risk locations and could be publically accessed through CorpsMap via the MVD website.

US Army Corps of Engineers

OPERATION WATERSHED UPDATE
2012 Interim Measures / Flood Fight Preparations
Birds Point New Madrid Floodway

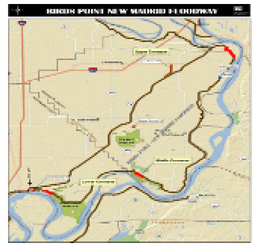
Mar 27, 2012

"Make Safe & Stable Operations"

Memphis District

Risk and Consequences

During the flood of 2011, three reaches of the Birds point New Madrid frontline levee were crevassed activating the floodway in an effort to provide relief to the city of Cairo and surrounding areas. Activation of the floodway resulted in degradation of these three reaches to an elevation below authorized grade. During the summer of 2011, these three crevasses were restored to a minimum elevation of 51.0 on the Cairo gage. Currently, all three crevasses are below authorized grade of 62.5 on the Cairo gage, which could potentially re-activate the floodway and cause severe damages individuals within the floodway, as well as damage to the work already performed at each three sites.



Risk Management Status

Currently, a Multiple Award Task Order Contract (MATOC) is being developed by the Memphis District with an advertise date of 31 March 2012 and a contract award on 30 May 2012. Restoration of the frontline levee to pre-operational levels must be done so in a manner that does not create an unacceptable imbalance of risk within the confluence area. Once the project is constructed, the threat for catastrophic failure diminishes.

Construction/Interim Measures

The interim measures consisted of constructing a temporary structure with HESCO bastions at the Upper Crevasse location. Surveys and borings are required to complete the plans and specs. Each Crevasse will be awarded as a separate task order, and interim heights are also being considered.

Image 1 — Aerial photo of Cairo and Vicinity

Flood Fight Preparations

Mobilization of District forces will take place in two successive phases. Activities required under Phase I and Phase II will be performed prior to or at the time the designated river stages are reached. Since some activities need to be performed prior to designated Phase I and Phase II stages, each area or sector will develop and maintain a checklist of activities to be performed, based on river stages and local conditions. Flood fight rosters will be updated and training on both traditional and innovative flood fight techniques will be conducted. Requests have been made to the Engineering Research and Development Center (ERDC) to provide smartphones which use the phone's GPS, camera, and data capabilities to collect field data and automatically upload it to a server database. Maintenance has been done on pumps and flood fight supply inventories have been replenished and staged for rapid deployment. Tabletop exercises playing out a levee breech scenario was conducted in Feb. with local Emergency Management officials, FEMA, MEMA, and the Corps.

Contacts

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Area Engineer: Donny Davidson (573) 333-1043
donny.d.davidson@usace.army.mil

The Caruthersville Area Office is located at 706 Harry S. Truman Boulevard, Caruthersville, Missouri 63830-1268

Flood Fight Phase Mobilizations

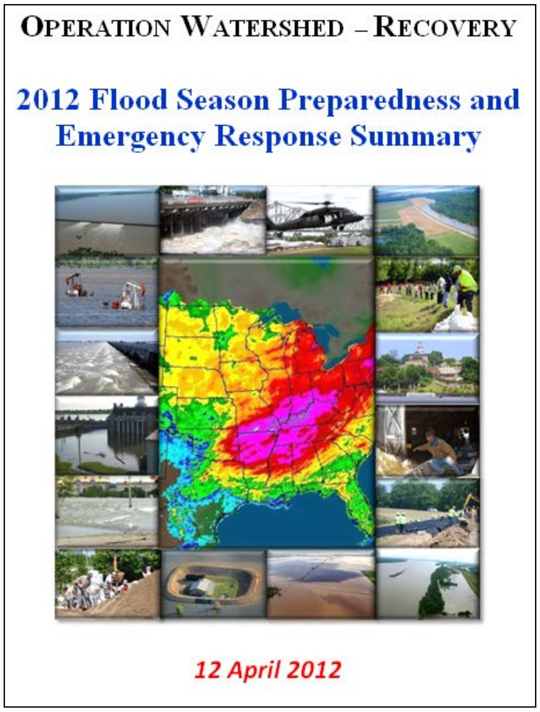
Information stated below is based on the Cairo Gage station

Flood Stage:	40 ft.
Phase I Mobilization:	47 ft.
Phase II Mobilization	49 ft.

Link to NWS site for current stage forecast conditions

Figure VI-21. Risk Management Information Paper for Birds Point-New Madrid Floodway

d. Flood Season Preparedness and Emergency Response Summary Report. This summary report was developed to capture in general terms, the efforts the Corps has undertaken to manage and mitigate risks associated with the flood of 2011 and in preparation for the next flood event (figure VI-22). It was intended to be used as a tool in conjunction with other OW-R products to communicate both internally and externally the risks which remain in the wake of the 2011 Flood event. The document includes discussion of the 2011 Flood, damages and repair needs, recovery needs and strategy, interim plans for reservoir/floodway operations, and development of a regional risk communication plan and products. This summary report was distributed directly to Federal and State partners and was also served through the MVD Flood Risk Management website.



2012 Flood Season Preparedness and Emergency Response Summary

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Figure VI-22. 2012 Flood Season Preparedness and Emergency Response Summary Report

3. Residual Risk/Risk Communication. Effective risk management depends greatly on well coordinated and executed communication. Carefully planned internal and external communication processes were implemented to more effectively execute the MR&T recovery process and inform future flood preparedness efforts. A focus on regional consistency, assessment of best practices, and lessons learned from the 2011 Flood event further informed the development and implementation of a regional communication plan for this MR&T System recovery effort.

a. Regional Communication Plan. A Regional STRATCOMM and Communication Plan was established in March 2012 (Appendix J, *MR&T System Recovery Strategy*) to serve as a framework and guidance for both the internal and external transfer of OW-R information via CorpsMap, fact sheets, talking points, presentations, press releases, social media, and website. The communication plan also highlighted some of the key participants and groups with whom regular communication is required (e.g., stakeholders, levee districts, congressional, IRTF, State emergency managers, etc). It is important that this shared responsibility be well coordinated and controlled to ensure our communications are responsive, purposeful and consistent. All requests for OW-R information from outside the Corps should be directed through the district and MVD Public Affairs Officer to secure timely response from the appropriate management or technical personnel. The regional communication plan also establishes clear protocols by which information will be appropriately vetted before transmission via any of the primary communication outlets.

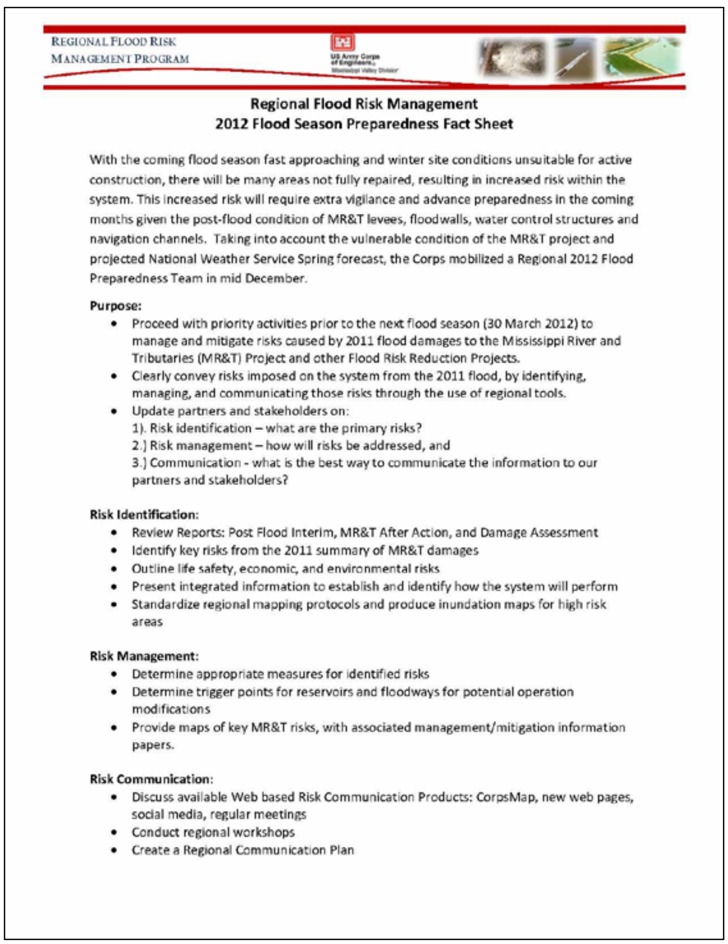
b. Interagency Recovery Task Force. An IRTF was established to create a multiagency forum to discuss and resolve a variety of regional flood risk management challenges by collaborating and combining solutions for short- and long-term recovery/mitigation/preparedness efforts (see Section VIII, *Interagency Recovery Task Force*). The IRTF is comprised of lead Federal and state agencies directly involved in the assessment, documentation and repair of damaged flood risk management and navigation infrastructure. This multi-agency group conducted meetings at different locations throughout the region as necessary to coordinate and enhance the recovery and preparedness efforts. The IRTF was very interested in maintaining real-time tracking and awareness of basin-wide recovery efforts. This was accomplished largely through the CorpsMap site with occasional group emails on important developments.

c. Regional Flood Season Preparedness Workshop. A workshop and Webinar (figure VI-23) was developed and conducted in early 2012 to advance regional communication and coordination of flood season preparedness between MVD, six Mississippi Valley Districts, Federal and State partners. The workshop was broken into two primary sections which focused on:

Mississippi Valley Regional Risk Overview - risk identification, management, and communication showcasing publically available regional tools (e.g., CorpsMap and Flood Preparedness website)

District Case Studies - District overviews and examples of flood season preparedness for high risk areas in the system, showcasing best practices and lessons learned from the 2011 Flood.

The workshop was well attended with over 80 participants and the net result was improved regional situational awareness with partners more fully understanding the current elevated risks on the system and how they can more effectively work with the Corps and public in addressing those risks. Workshop materials were made available through an MVD Flood Season Preparedness website.


REGIONAL FLOOD RISK MANAGEMENT PROGRAM

Regional Flood Risk Management
2012 Flood Season Preparedness Fact Sheet

With the coming flood season fast approaching and winter site conditions unsuitable for active construction, there will be many areas not fully repaired, resulting in increased risk within the system. This increased risk will require extra vigilance and advance preparedness in the coming months given the post-flood condition of MR&T levees, floodwalls, water control structures and navigation channels. Taking into account the vulnerable condition of the MR&T project and projected National Weather Service Spring forecast, the Corps mobilized a Regional 2012 Flood Preparedness Team in mid December.

Purpose:
- Proceed with priority activities prior to the next flood season (30 March 2012) to manage and mitigate risks caused by 2011 flood damages to the Mississippi River and Tributaries (MR&T) Project and other Flood Risk Reduction Projects.
- Clearly convey risks imposed on the system from the 2011 flood, by identifying, managing, and communicating those risks through the use of regional tools.
- Update partners and stakeholders on:
  1). Risk identification – what are the primary risks?
  2.) Risk management – how will risks be addressed, and
  3.) Communication - what is the best way to communicate the information to our partners and stakeholders?

Risk Identification:
- Review Reports: Post Flood Interim, MR&T After Action, and Damage Assessment
- Identify key risks from the 2011 summary of MR&T damages
- Outline life safety, economic, and environmental risks
- Present integrated information to establish and identify how the system will perform
- Standardize regional mapping protocols and produce inundation maps for high risk areas

Risk Management:
- Determine appropriate measures for identified risks
- Determine trigger points for reservoirs and floodways for potential operation modifications
- Provide maps of key MR&T risks, with associated management/mitigation information papers.

Risk Communication:
- Discuss available Web based Risk Communication Products: CorpsMap, new web pages, social media, regular meetings
- Conduct regional workshops
- Create a Regional Communication Plan

Figure VI-23. Regional Flood Preparedness Workshop Fact Sheet

d. CorpsMap. CorpsMap is the single authoritative source for the Corps' national geospatial data assets. It is a geospatial web platform that is sponsored by HQs and denoted in the Engineer Regulations as the *USACE Enterprise Web Geospatial Platform*. Until 2011, CorpsMap was an exclusive internal Corps system. The MVD regional GIS cadre worked with both the regional OW-R management team and the national GIS team to establish one of the first External CorpsMap sites: http://geo.usace.army.mil/egis/cm2.cm26.map?map=mvd_ows with many capabilities specific to the communication needs for OW-R. MR&T repair and risk locations, project information papers, and up-to-date construction facts sheets were some of the key products being served via CorpsMap figure VI-24).

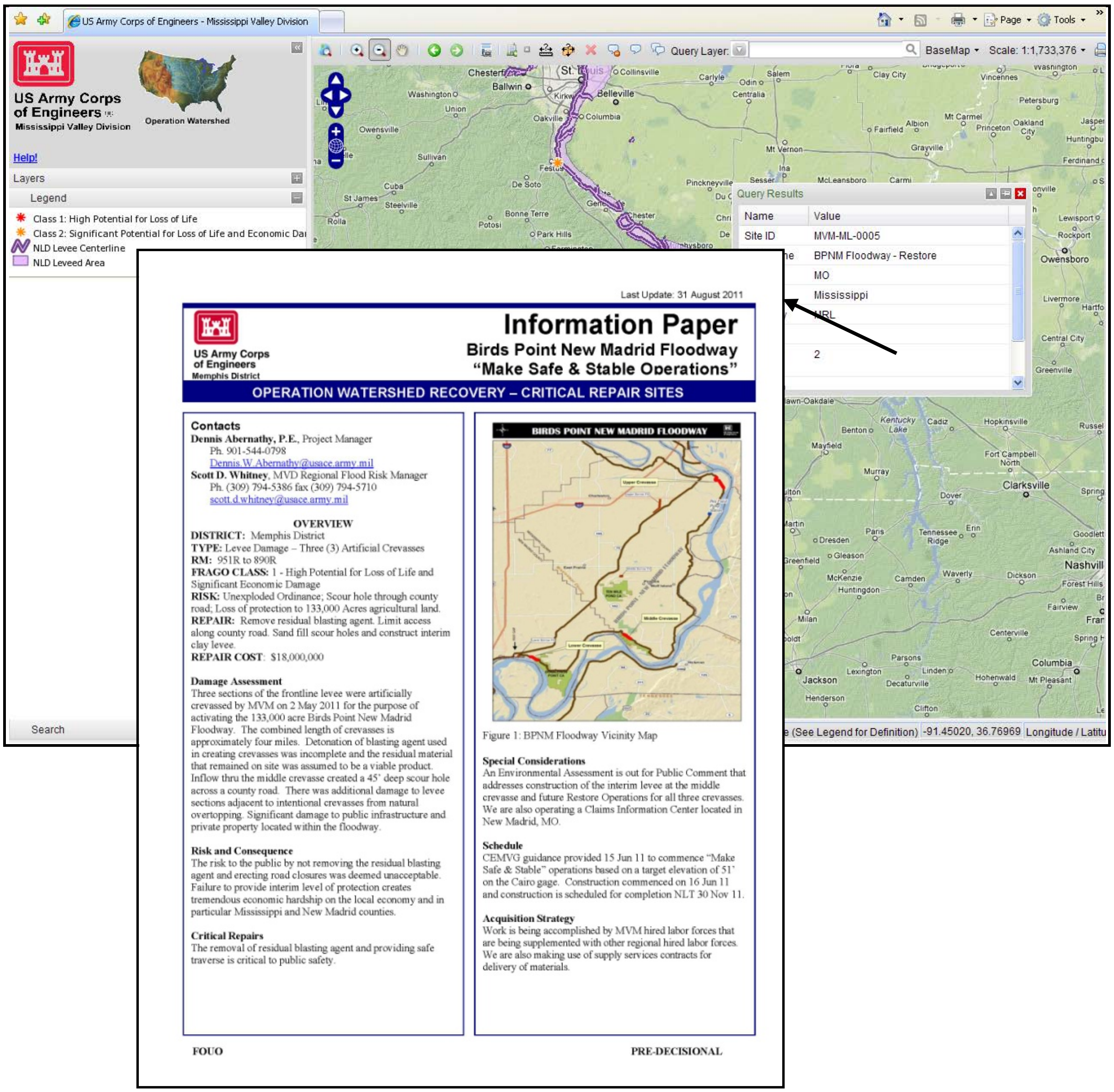


Figure VI-24. CorpsMap Displaying MR&T Risk and Recovery Information

e. Website and Brochures. A new MVD regional FRM website was established as a primary conduit for external communication and access to a wide range of regional flood risk management documents and information (figure VI-25). The "webmaster" for this new website ensured appropriate vetting of "public" documents and information before posting. Brochures were also generated and served via this website to provide easily understandable information on key Corps FRM tools and programs.

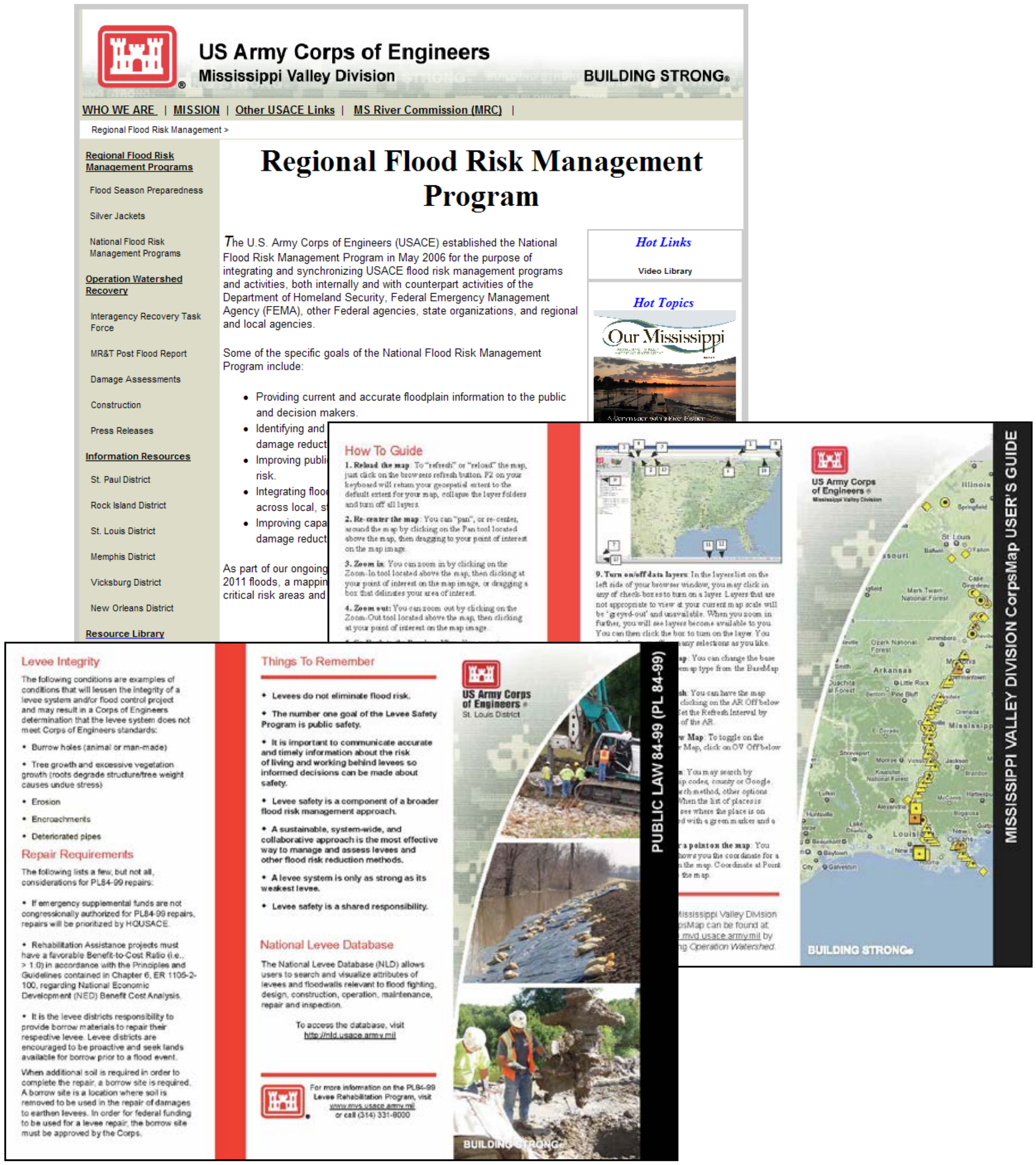


Figure VI-25. USACE Flood Risk Management Website and Brochures

E. MR&T System Recovery. While damage assessment work was still proceeding, MVD initiated construction efforts using its hired labor crew to facilitate rapid interim repairs to the BPNM Floodway. Private contractors soon followed on other critical repairs elsewhere in the system. A repair strategy of reducing risk by systematically identifying and repairing the sites that presented the greatest overall risks was applied to bring the MR&T System is back to its pre-2011 flood condition. Recovery efforts also included assessment of vulnerabilities that impact other Corps programs and activities such as the channel improvement program and ongoing construction efforts under other authorities.

The following sub-sections provide further information on how major MR&T component recovery efforts are proceeding for reservoirs, levees, floodways, etc.

1. Reservoirs. The only MR&T reservoir that experienced flood damages (other than typical recreation impacts beyond the scope of this report) was Wappapello Lake. Damages incurred included spillway, exit channel, roads, and utilities. Immediately after the flood, the Corps and MODOT worked together to construct a temporary by-pass for Highway T, a main thoroughfare which was washed out during the flood. A temporary license was issued to allow MODOT to use the Corps recreation road, which the Corps constructed almost immediately following the flood. MODOT was responsible for paving, striping curbs, and signage. The by-pass road was available to the public less than a month after the flood. Portions of the damages to the Wappapello Lake Project resulting from the 2011 Flood are being repaired with supplemental funding, but many items remain unrepaired. The district performed an investigation of the limited use spillway's capacity to efficiently pass a PMF event. The investigation used current spillway hydraulic criteria to determine if the spillway will pass a PMF event as defined in the current Water Control Manual. Results indicate that under the current conditions, the limited-use spillway is able to pass the design flood event. Repairs are underway to the exit channel and spillway to fix the most immediate issues; however, funding is still required to completely address the extent of damages. Road repairs are being performed with the supplemental funding and will be completed in FY13. Utilities, including some temporary, have been repaired, final repairs still remain pending road work. Additionally, several of the minimally acceptable items including recreation areas, roads, and utilities have been repaired or will be repaired with supplemental funding.

2. Levees and Floodwalls Systems. Immediate Risk Reduction Measures that have been implemented to date include needs of the MR&T levees and floodwalls that were defined as Classification 1 projects in accordance with the Hot Spot Project FRAGO. These projects remediate issues identified during the 2011 event that are likely to cause failure prior to a 25-year event. For a prioritized listing of immediate needs for the MR&T Project levees and floodwalls, with estimated construction costs and completion dates, see table VI-1. For a discussion of each of these projects, see the appropriate levee system discussion in Section IV. D2.

Long-term needs of the MR&T levees and floodwalls were defined as Classification 2 and 3 projects in accordance with the FRAGO. These projects remediate issues identified during the 2011 event that could possibly lead to failure prior to a 25-year event. For a prioritized listing of the immediate needs for the MR&T project levees and floodwalls, with estimated construction costs and completion dates, see table VI-2. For a discussion of each of these projects, see the corresponding levee system discussion in Section IV D2.

3. Floodways

a. Bird's Point-New Madrid Floodway. In order to provide a stable base for flood fight operations by November 30, 2011, the MVD Commander issued a memorandum directing the MVM to implement operations to make the floodway safe and stable based on a target stage of 51 feet on the Cairo gage. Restoration of the crevassed section for safety and stability purposes was later expanded, and authorization and funding provided, to include reconstruction of the levee at the upper inflow crevasse to provide FRM up to a stage of 55 feet on the Cairo gage. As of May 2012 the Floodway crevasses had been repaired to varying degrees as follows:

- At the upper crevasse, the current height of earthen levee is equal to a stage of 51 feet on the Cairo gage. The crevasse length is 9,000 feet long. Polyethylene sheeting has been placed on the river side slope around this crevasse to prevent erosion damage from waves, and 4 feet of HESCO bastions have been placed on top of the reconstructed levee to raise the grade to a stage of 55 feet on the Cairo gage.
- At the middle crevasse, the current height of earthen levee is equal to approximately 53 to 55 feet on the Cairo gage, depending on location. This levee's clay cap has not been fully replaced.
- At the lower crevasse, the current height of earthen levee is equal to approximately 53 to 55 feet on the Cairo gage, depending on location.

As of July 2012, the Corps was moving forward to fully restore the BPNM Floodway mainline levees to the pre-2011 Flood levels by December 2012.

b. Morganza Floodway. Repair and recovery efforts at the Morganza Floodway have focused on the damaging scour that occurred in the tailbay during the 2011 operation. Operational records have been analyzed, literature surveys and hydraulic analyses have been performed to determine the cause of this scour, and commercially available energy dissipation products have been assessed for appropriateness. This effort is expected to result in a preliminary scour protection design and material specification. The design and material of this design will then be tested and modified through a physical model study being performed at the ERDC in Vicksburg, MS. A physical model study was chosen instead of a numerical model because flow conditions including a hydraulic jump are generally too unsteady and dynamic for numerical simulation. Furthermore, at this time, the science of applying stone sizing equations using numerical model results below a hydraulic jump is a work in progress.

The Morganza Control Structure physical model will be used to develop scour protection for low tail water conditions when only some of the gates are in operation. The model will also help determine weir coefficients and identify necessary modifications to the stilling basin so that it can function properly at headwater levels greater than 56 feet (the original studies anticipated operation at a headwater of 56 feet or less, but recent floods stages have been much higher without reaching the flow trigger for floodway operation). Because operation of the structure typically involves a gate being opened when adjacent gates are closed, the model will represent more than a single gate bay in order to address typical conditions. The current stilling basin is not adequately designed or constructed to be able to handle discharges with a headwater elevation that is higher than 56 feet. The physical model study will look at high headwater scenarios to help determine whether or not modifications are needed in the stilling basin. The study is expected to require 9 months to complete.

The project has many inoperative piezometers and inadequate foundation pressure relief wells. A set of ten new piezometers and one new one are needed. The relief wells need reconstructed. After the repairs, the uplift pressures under the stilling basin can be measured and used to check against computed pressures used to analyze the stability of the stilling basin. An initial estimate for this work is approximately $2.42M, but a plan has not been developed. The latest estimate for repair of tailbay scour holes by filling them with riprap is about $20 million. The plan and estimate for repair of the damaged derrick stone apron were under development when this report was prepared.
In additional to the above mentioned items, part of the post recovery plan should include plans to achieve an appropriate level of freeboard on the structure associated with the authorized operational trigger discharge of

1.5 million cubic feet per second. An assessment should be conducted to determine if changes to the water control plan are warranted and studies examining various structure modifications should be considered as part of the post-flood recovery. The range of structural modification options evaluated should not be limiting, but should include raising the structure, gates and guide levees, designing a stilling basin with proper baffle blocks, or a retention basin in the tailbay to achieve a desired tail water elevation during operation. The current difficulty in operating the structure during large flood events warrants the need for investigations into improving performance.

c. Bonnet Carré Spillway. The Bonnet Carré Spillway did not sustain significant damage during its 2011 operation, so no repair operations have been undertaken. A cost estimate for replacement of the destroyed gage at the lakefront is under preparation and will be considered as part of the overall streamgaging program, while sedimentation in the Spillway will be removed over time by private sand-hauling companies.

d. Old River Control Complex. The most significant damage incurred at the ORCC was sedimentation in the inflow and outflow channels of the Low Sill and Auxiliary Structures, which raises stages and causes bank erosion. Cost estimates and specifications have been prepared for removal of this sediment by dredging, and funding has been authorized. This proposed dredging plan is now under consideration for possible environmental and flowline impacts, but is expected to be performed by the end of FY 2013.

Limitations of operations at the Overbank Structure related to the damage to the tailbay section restrict the flexibility of the ORCC to handle a flood of longer duration or higher magnitude then the 2011 Flood. This condition also hampers the ability of the ORCC to adjust flow allocations between the structures to handle an emergency, such as a flow rejection at the Hydro power plant, or errant vessels near the structure intakes. The limitations at the Overbank Structure consist of limiting the discharge through the structure to prevent further damage to the tailbay section. Cost estimates and specifications need to be prepared for repairing the tailbay section armored with gabions.

4. Backwater Areas. Because they were not operated during the 2011 Flood, the St. Francis River, White River, Yazoo River, and Red River Backwater Area levees did not directly sustain any damages and no repairs were required for these MR&T components.

5. Interior Drainage Systems. Rain events during the flood impacted interior drainage structures during the 2011 Flood. As noted in previous sections, some interior drainage structures were not operable as a result of the river flooding. Certain areas would have experienced increased flooding and damage had it not been for drought conditions in the lowest part of the valley. Overall there was very little damage to interior drainage components. Consequently, few immediate repair needs were identified. One notable exception was the scour damage at Bayou Chene; where on 20 May, the Corps supplied five barges of 600 stone to be placed in the failure gap. Construction was completed 25 May 11.

6. Channel Improvements

a. Damages Due to the Flood. The Channel Improvement community identified a significant number of sites that sustained damage to articulated concrete mattress (ACM) revetment and dikes during the 2011 Flood, 44 of which could have an impact on system performance if not repaired. Flood damage to channel improvements was categorized as either critical or non-critical. Critical sites were primarily those revetments that are located in close proximity to the mainline Mississippi River Levee. Revetment failure at these locations could result in a threat to the integrity of the mainline levee. Two critical sites not located in close proximity to a mainline levee are Merriwether-Cherokee and President's Island in the MVM reach of the river. At these locations, the river scoured the overbank to the degree that channel relocation would have occurred if the flood had been of sufficient duration. If these relocations had occurred, the impacts to the channel upstream and nearby levee would have been devastating.

Damage to revetments includes upper bank erosion, toe scour, and areas of revetment failure. Primary damage to dikes includes flanking, blowouts, expansion of existing notches, downstream scour pockets in the bankline, and overall structure degradation. If left unrepaired, this damage will grow over time presenting a bigger threat to the integrity of the flood risk management and navigation systems and increasing the cost of repairs.

Following is a brief description of the proposed repairs for the items discussed in Section VI.C.6.

i. Memphis District

Chute of Island 8. The recommended repair includes grading to produce stable slopes and placing two layers of ACM since the bank is susceptible to severe attack from both river currents and prop wash from navigation traffic. In addition to two layers of ACM, an extra thickness of upper bank paving (3 to 4 feet total) will be placed in selected areas to protect the remaining tree screen.

Merriwether-Cherokee. The recommended repair includes rebuilding top bank with stone, constructing a stone baffle landward of top bank in the scour hole, pumping of dredge fill in between the stone baffle and rebuilt top bank and placing ACM to protect the riverbank slopes. It should be noted that this construction is to reduce the risk of a river cutoff and protect the alignment of the navigation channel. The scour hole and surrounding area will not be protected from flood flows until a new setback levee is constructed.

President's Island. The recommended repair includes rebuilding top bank with stone, constructing a stone baffle landward of top bank in the scour hole, pumping of dredge fill in between the stone baffle and rebuilt top bank and placing ACM to protect the river bank slopes.

Below Richardson Landing. The recommended repair consists of restoring the top bank and overbank to pre-flood conditions.

Randolph Dikes. The recommended repair consists of placing stone from Tieback 2 to 1,100 feet downstream, repairing major failures along trail dike and tieback dikes, restoring crown widths to design widths and riverside slopes to approximate angle of repose and restoring dike to grade and section the entire length of the structures.

Cache-Cairo. A detailed geotechnical investigation was initiated to formulate the ultimate repairs for this area. The preliminary recommendation is to address the toe scour and over-steepened banks with a two-phase approach. This will include placement of Graded Stone C along the toe and the upper bank slopes, followed by placement of ACM.

Ensley Revetment. The recommended repair consists of repairing the ACM and top bank to pre-flood conditions.

Walnut Bend Revetment. The recommended repair consists of repairing the ACM to pre-flood conditions. This will require grading the bank and the placement of about 5,100 squares.

Oldtown Revetment. The recommended repair consists of restoring the AVM and top bank to pre-flood conditions. This will require the placement of about 10,500 squares. Smaller areas of failure will require grading and the placement of stone to restore slopes.

ii. Vicksburg District

Delta Mat Casting Field. The damage to the casting field has been repaired and was completed on July 27, 2011. Sediment was removed and placed in the scour holes. Some additional sand was required to fill all the holes. The office and laboratory required extensive repairs including replacing insulation, windows, heating and air conditioning systems and the water heater. The laboratory required repairs including replacing electric motors. This effort was accomplished outside the "normal" flood recovery process so as to minimize the adverse impacts to the casting season.

Walnut Point/Kentucky Bend. The recommended repair includes the placement of approximately 24,800 squares of ACM with the associated bank grading and upper bank paving.

Kempe Bend Revetment. The recommended repair includes repairing 5,000 feet of ACM requiring the placement of about 20,000 squares. No grading or placement of upper bank paving is required. This repair was completed during October 2011 by placing 19,835 squares of ACM.

Leland-LaGrange Revetment. The recommended repair includes the construction of a 1,000-ft long closure dike across both the riverside and landside ends of eroded channel and, possibly a 500-ft long baffle dike between the other two dikes.

Dennis Revetment. The recommended repair consists of placing approximately 8,800 squares of ACM. No grading is required at this site.

Cypress Bend Revetment. The recommended repair consists of placing about 6,000 squares of ACM. No grading is required at this site.

Mayersville Revetment. The recommended repair consists of grading the bank and placing approximately 3,200 squares of ACM and upper bank paving.

Goodrich Revetment Upstream Extension. The recommended repair consists of grading the bank and constructing a 24-inch thick riprap revetment.

Milliken Bend Revetment. The recommended repair consists of placing approximately 10,000 squares of ACM. No grading is required.

Hardscrabble Revetment Downstream Extension. The recommended repair consists of constructing 1,000 linear feet of new ACM. The work will require grading the bank, placement of approximately 4,000 squares of ACM and placement of upper bank paving.

Gibson Revetment. The recommended repair consists of placing approximately 3,600 squares of ACM. No upper bank paving is required at this site.

Morville Revetment. The recommended repair consists of placing approximately 6,000 squares of ACM. No grading is required at this site.

Bougere Revetment. The recommended repair consists of grading the bank and placing approximately 43,100 squares of ACM and upper bank paving.

iii. New Orleans District

Third District. The recommended repair consists of constructing a rock berm to stabilize the bank.

Avondale Bend Revetment. An additional layer of ACM was placed to prevent the scour from enlarging.

Port Allen Revetment. An additional layer of ACM was placed to prevent the scour from enlarging.

Saint Gabriel Revetment. The repair consists of placing an additional layer of ACM to prevent the scour from enlarging.

Greenville Bend Revetment. An additional layer of ACM was placed to prevent the scour from enlarging.

Alliance Revetment. The recommended repair consists of constructing a stone stability berm.

b. Residual Risk

i. Project Design Flood. With the river channel and the protection and training works in their current state, in the event of the Project Design Flood (PDF), there would be a significant increase in the existing damage to the structures. Considering the increased magnitude of a PDF, damage at other locations will probably occur. At Merriwether-Cherokee, the main channel would, most likely, change course to a path across the existing overbank area. In the event of this change, channel instability upstream would, most likely, occur resulting in threatening the integrity of the adjacent mainline levees. Also, in the absence of the private levee that existed prior to the 2011 Flood, the mainline levee just downstream of the junction of the two levees may not have sufficient height to contain the PDF. At President's Island, the main channel would, most likely, change course to a path across the existing overbank area. Although the effects on the river channel would be less severe than at Merriwether-Cherokee, there would be some channel instability. In addition to channel instability, the effects on the nearby port facility could be severe in the event of the channel changing course. At the numerous locations where the top bank is close to the levee toe and erosion was experienced in 2011, the erosion during a PDF could approach the levee and threaten its integrity.

MVN was the only district where the 2011 Flood approached or exceeded project flood flows and stages in portions of the system. The 2011 flood informed MVN of numerous areas where there are freeboard issues. The Atchafalaya Basin Levee District, which has responsibility for the west bank Mississippi River levee from the vicinity of Old River to Donaldsonville, identified 36 locations along the levee where freeboard during the 2011 event was less than authorized. The 2011 operation of Bonnet Carre and Morganza structures considered deficient levees and floodwalls in the New Orleans area. During the flood event, there was less than one foot of freeboard on the gates at Morganza, which calls into question the ability of the system to pass project flood flows in this area. The deficiencies of Charenton Floodgate and Bayou Sorrel Lock to authorized project grade have been documented in Corps documents as well as periodic inspections. Although the 2011 Flood was safely passed through MVN, the performance of the MR&T system in MVN for project flood conditions, even with major flood fighting, is in question.

ii. Repeat of the 2011 Flood. With the river channel and the protection and training works in their current state, in the event of a repeat of the 2011 Flood, there would be an increase in the existing damage to the structures. At Merriwether-Cherokee and President's Island, the main channel may change course, depending on the level of the proposed repairs. At the numerous locations where the top bank is close to the levee toe and erosion was experienced in 2011, the erosion during a repeat of this flood could approach the levee and threaten its integrity. See Appendix D, *Channel Improvements* for tables showing non-critical repairs and more comprehensive descriptions of each phase of the Project, estimated costs, and preliminary schedules for the MVM, MVK, and MVN Districts.

7. Streamflow/Channel Capacity

a. Streamflow. On the Mississippi River in the New Orleans District, the two different discharge measurement techniques, Acoustic Doppler Current Profiler (ADCP) and conventional Price meter, have yielded different discharge values at higher flows, with the ADCP measurement consistently lower than the conventional measurement, as shown in figure VI-26.

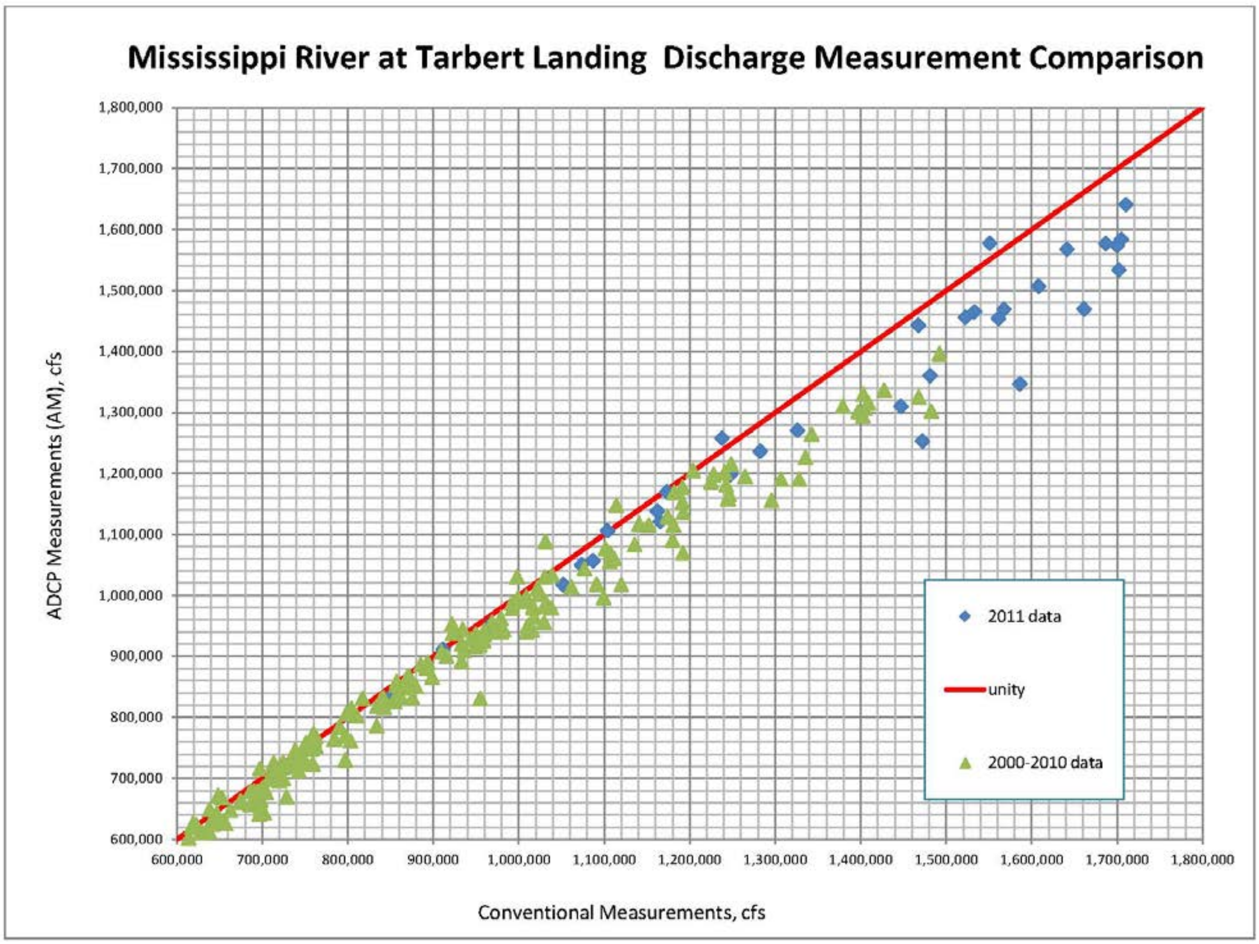


Figure VI-26. Comparison of Conventional and ADCP Measurement Data

Efforts to improve both measurement techniques have resulted in better consistency between the measurement techniques; however, leading into the 2011 flood, the differences between the two techniques still remained. Overall, ADCP measurements taken during the 2011 flood showed similar trends as reflected in data taken over the period 2000-2010 and in the average rating curve used for the levee system evaluation. Note, in 2008, because the overbank range was not cleared, measurements during the flood event were taken in the vicinity of Angola, approximately 4 miles downriver. Side by side measurements were taken by both USGS and USACE at the Angola site due to the difficulty in making a measurement using a Price meter at that site. After the 2008 flood, USGS and USACE formed a fusion team to further evaluate discharge measurements taken with the two techniques. Side by side measurements were taken in 2009 at Natchez by USGS and USACE crews and yielded the same trend as those at Tarbert Landing and Angola (figure VI-27).

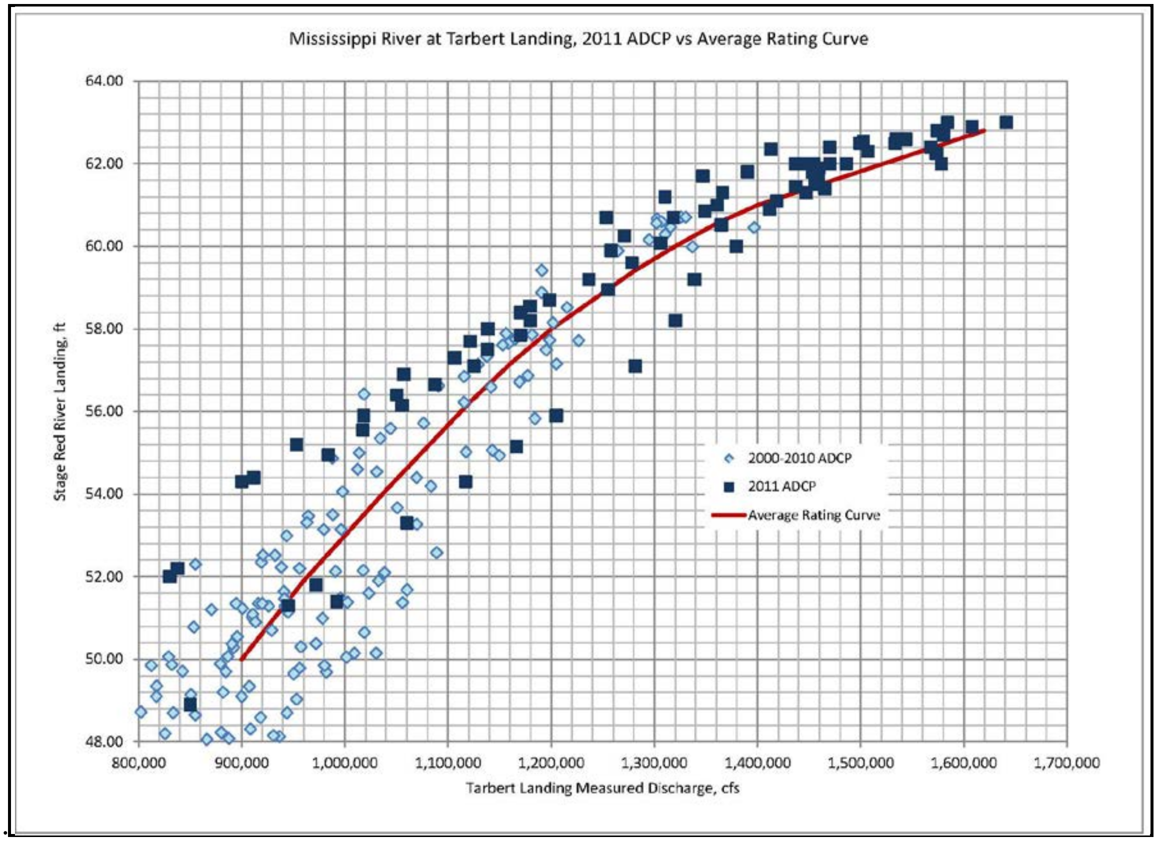


Figure VI-27. ADCP Measurements and Rating Curve – Red River Landing

Although the analysis was not complete at the time this report was prepared, the team found that, overall, the quality of the ADCP measured discharges was consistent with the conditions being measured. Where discharges were rated poor, it was typically due to fluctuations in the discharge that appeared from the data to be real, and not a function of poor instrument performance or poor field technique. Issues found in equipment and field technique were minor; it was concluded there would be little effect on the discharge measurement. Nearly all measurements were characterized by a standard log or power velocity profile, with the exception of the measurements made on the Mississippi River above and below the Bonnet Carré Spillway.

After the 2011 Flood, a new USACE and USGS team investigated stream flow measurements to address several concerns. Four areas were identified for assessment:

- Measurement Techniques
- Causes of Discharge Variability in the Mississippi River
- Effects of Discharge Variability on Water Control
- Adequacy of Measurement Program, Including Spatial and Temporal Coverage

To date, the team has initiated a quality control review of the majority of measurements taken on the main stem Mississippi and Atchafalaya Rivers from Vicksburg south, analyzed flow measurements using the two techniques, and developed an action plan to look at the causes of discharge variability. Analysis of the ADCP and conventional Price meter measurements is still ongoing. Continued investigation of the differences in the two measurements will inform not just the MR&T project but other projects. Continued analysis of the discharge pulsing is ongoing; processing of the measurements has resulted in the results shown on figure VI-28. The discharge variability may be due to one or more factors in combination. Possible reasons for the discharge variability are:

- operation of the ORCC; operation of Morganza Floodway;
- resistance to flow caused by bedform changes, possibly enhanced or accelerated by operation of the flood and water control structures; and
- transition in and out of discrete secondary flow structures within the discharge measurement range.

Discharge measurements at Arkansas City, Vicksburg, and Natchez show variability that may also be indicative of pulsing. In addition, when viewed in context of a stage-discharge rating curve, measurements taken at Vicksburg and Natchez during the period May 11-14 show anomalies similar to those observed for Tarbert Landings. Arkansas City discharge measurements were taken at several locations in the Mississippi River and that may also have contributed to the variability.

b. Channel Capacity. Surveys taken after the 2011 Flood in portions of the river within the MVM boundaries show no appreciable decrease in cross sectional area as a result of the 2011 Flood. Four areas of the river within the MVM experienced overbank scour, which, if not repaired, could lead to cutoffs. If cutoffs developed, the length and cross sectional area of the river would have changed which in turn would change stages for project flood flows.

At the time this report was prepared, post-flood survey data of the Mississippi River have not been taken in MVK. In 2012, the MVN performed hydrographic surveys of the Mississippi River from Baton Rouge up river to the MVK boundary. Analysis of the survey data is ongoing; preliminary results show deposition in the channel. Channel surveys in the inflow and outflow channels of the Old River Control Low Sill and Auxiliary Structures show substantial deposition in portions of the channel that could potentially affect structure operations during future events.

In 2010, the MVN funded a geomorphic analysis and comprehensive modeling effort of the Mississippi River in the vicinity of the ORCC. ERDC performed discharge, suspended sediment, and bedload measurements in 2010 and also during the 2011 Flood to gain a better understanding of flow and sediment diversion from the Mississippi River into the three inflow channels within the complex.

A specific gage analysis was performed on Mississippi River gages in MVK and MVN as part of the geomorphic assessment. For the period of record, the majority of the gages on the Mississippi River in the two districts showed a trend of increasing stage for a given flow. The gages on the Atchafalaya River showed a trend of decreasing stage for a given flow. Looking at the period 1973 – 2010, the analysis found some trend of increasing stage at Natchez and Red River Landing, but overall, there was no stage trend apparent in the two rivers.

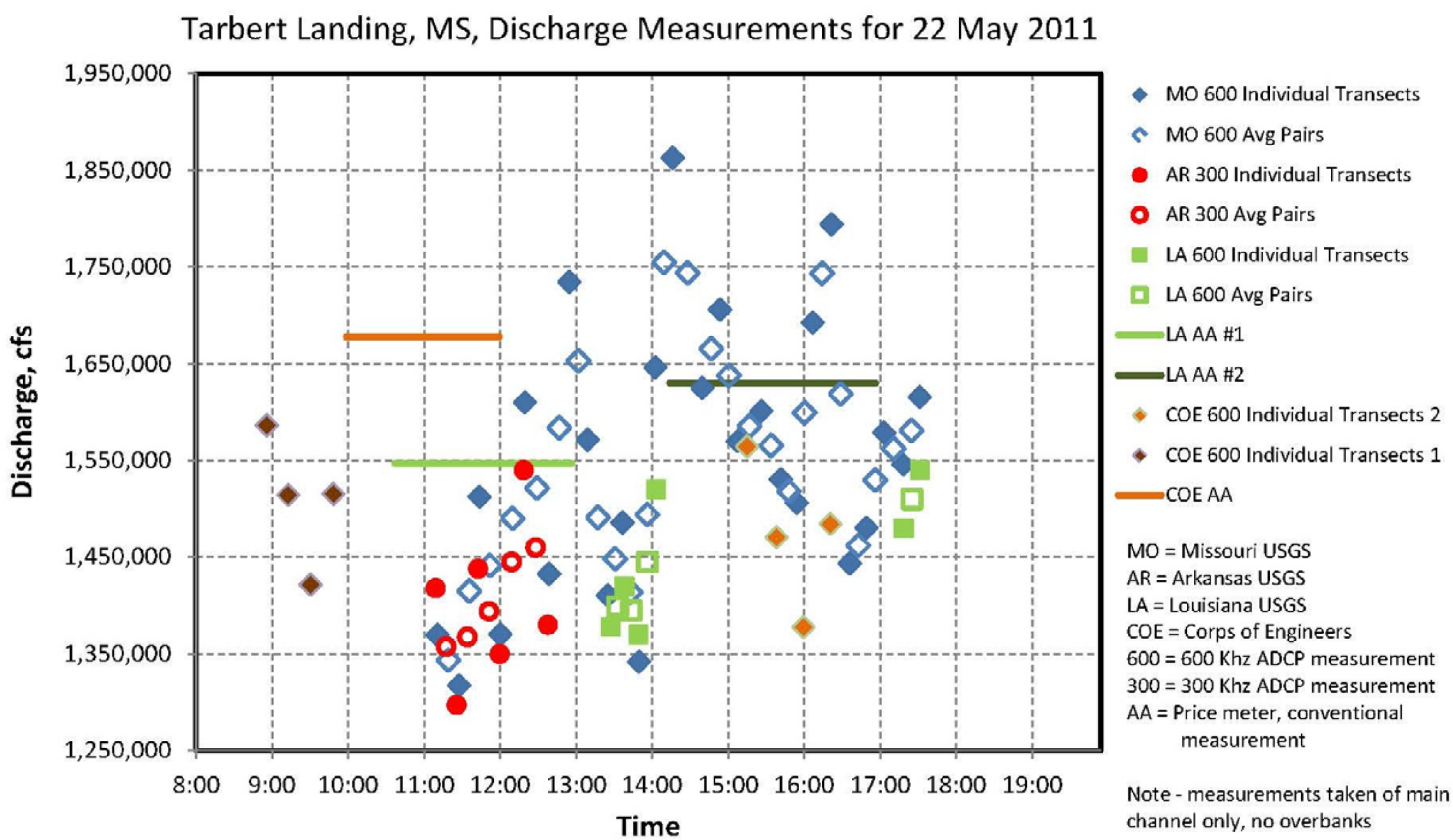


Figure VI-28. Gage Results for Key Locations

During the Flood of 2011, higher than historical stages were observed at several locations, for a given discharge. This indicates that the flowline for the river may be rising. However, specific gage analyses for discharges at or below bank full do not indicate a significant trend. If the changes in stage observed at flood flows were caused by the loss of channel capacity due to aggradation, one would expect to see the same trend for lower flows.

The geometric data analysis incorporated comparative cross sections and contour maps developed from historic hydrographic surveys to assess channel geometry changes that have occurred since the construction of the low sill structure. Analysis of the comparative cross sections indicates a generally shallower river channel in 2010 than existed in 1975 for the reach just upstream of the hydropower channel to just downstream of the auxiliary structure channel. The most notable changes were observed between the hydropower channel and the low sill structure channel, where approximately 25 to 30 feet of filling occurred between 1992 and 2008. Deposition in the range of 10 to 20 feet was also observed for the river channel in the vicinity of the low sill channel. Comparison of contour maps also indicates a reduction in river channel depths between the hydropower channel and the low sill structure channel from 1992 to 2004.

ERDC has compared 1992 USGS land cover with 2011 digital imagery for the portion of the Mississippi River between Old River and Baton Rouge; results of the analysis could determine if land cover changes have occurred that may have contributed to the increase stages.

Dr. Mead Allison has developed annual water and sediment budgets for the Mississippi River from Old River to Head of Passes. Dr Allison's sediment budget shows approximately 31% of the total sand load below ORCC goes into in channel and overbank storage between the complex and Bonnet Carre Spillway.

Given these uncertainties, it is not possible to positively attribute changes in flood stage to aggradation in the Mississippi River. However, the modeling analysis indicates that excess sediment is being passed downriver, and therefore any mitigation of this excess sediment should either have a neutral or positive effect on flood stages.

8. MR&T System Recovery Plan. The recovery of the system will require several construction, flood preparation, and operation-related activities. Construction repairs for levees, floodways, and some channel structures is needed to restore the system to its pre-flood status. The 2011 Flood exposed vulnerabilities in some water control plans for reservoirs that will need to be addressed. Similarly, the flood tested emergency operating plans for some floodways that will need to be updated. The flood confirmed a general suspicion that the capacity of the Mississippi River main channel has degraded over many years and potentially requires action to restore its capacity. Repairs and other measures will be addressed in a prioritized manner, but there will always be residual risk. Implementation constraints that delay work elevate risk by increasing exposure time to flood events. Although these repairs and measures are funded, some repairs require detailed design and lengthy contract advertisement as well as potentially long construction schedules. Some physical repairs require real estate actions, borrow pit acquisitions, environmental/cultural mitigation, etc that add complexity and time to project schedules. Prolonged implementation increases the cumulative flood risks. The Corps' flood fight teams and emergency managers will have to understand, monitor, and manage Project status, overall risks, and residual risks especially at the onset of flood seasons. Using documentation of the 2011 flood fight measures, the Corps and/or the levee districts have developed interim FRM measures to reduce risks. The construction schedule and its progress will be used to update the emergency operation plans for flood fighting and the operation of other MR&T system components.

F. ENVIRONMENTAL AND CULTURAL RESOURCES

1. Post-Flood Response to Environmental Issues. During and after the 2011 Flood, there were multiple efforts to study the behavior of sturgeon within the three primary spillways and to recover individuals collected below spillway outfalls. Sturgeon surveys were conducted around the crevasses within the Birds Point frontline levee at the BPNM Floodway once 14 days after floodway activation (May 16-19), but while the Mississippi River was still actively flowing into and out of the floodway, and twice to survey fish stranded in scour holes during recession of the floodwater (July 12-13, July 27-29). One live sturgeon was recovered during the May effort, and 25 sturgeons were recovered during the July surveys (two alive, 23 dead). The high rates of localized mortality were attributed to the low oxygen levels in the water within the scour holes (photograph VI-50). A similar result would be expected if sturgeon were trapped in borrow pits during receding flood elevations. All of the observed sturgeons were shovelnose sturgeon (*Scaphirhynchus platorynchus)*.

Photograph VI-50. Large Scour Hole Within the BPNM Floodway
As the floodwater receded, the dissolved oxygen level within the remaining water dropped below that required to sustain aquatic life, killing the fish trapped within the scour hole.

A Corps fisheries team conducted a similar effort to recover sturgeon trapped within the Morganza Spillway upon its de-activation. The team found no sturgeon. The dominant species identified by an electroshocking survey include silver carp, gizzard shad, bigmouth buffalo, gar, catfishes, silversides, and sunfishes. This survey also identified the presence of a few relatively rare species that include skipjack herring, mullet, and flathead catfish. Based on previous life history studies, many of the fishes observed were backwater species. In addition, five species of freshwater mussels typically found in backwaters were observed. Only a few riverine species were present. The long distance between the mainstem river and the spillway is the likely reason sturgeon were not found below Morganza.

During and immediately after operation of the Bonnet Carré Spillway, a multi-agency (Corps, USFWS, LDWF, and Nicholls State University) team attempted to recover sturgeon that entered the spillway. Sturgeon were collected using elecroshocking gear, seines, trawls, and gill nets for 24 days following the spillway closure on June 20. During this period, 19 pallid, 77 shovelnose, and one intermediate sturgeon were collected within the outfall of the spillway. These sturgeon were entrained but swam upstream towards the structure where they were readily captured. The majority of the collected specimens were relocated back to their habitat within the Mississippi River main channel while a subsample was retained for scientific study. Nineteen shovelnose sturgeon were fitted with telemetry transmitters to track their movement and were released below the spillway outfall. No sturgeon were detected moving past the remote receivers into Lake Pontchartrain, but monitoring cannot totally discount the probability of sturgeon wandering into the Lake.

To relieve the building pressure on backwater levees around Eagle Lake, MS from rising floodwater, the Muddy Bayou control structure was operated to allow floodwater to drain from Steele Bayou to Eagle Lake. At that time, it was believed that Eagle Lake was absent of Asian carp (silver carp (*Hypophthalmichthys molitrix)* and bighead (*H. nobilis)*), which are invasive species of fish, and that Steele Bayou contained a breeding population of Asian carp. The Corps and Mississippi Department of Wildlife, Fisheries and Parks (MDWFP) personnel conducted two fish surveys (on May 2 and August 10) of both Eagle Lake and Steele Bayou. The surveys observed no evidence of Asian carp within Eagle Lake and a substantial population within Steele Bayou (photograph VI-51).

It is believed that because of the significant length of time in which water flowed from Steele Bayou to Eagle Lake and the abundance of Asian carp in Steele Bayou, Asian carp very likely entered Eagle Lake. However, it is unknown at this time if large enough populations of Asian carp were introduced to Eagle Lake to establish permanent populations. Subsequent surveys by MDWFP did not detect Asian carp nor have there been any reports from local residents of jumping silver carp. Asian carp that may have entered and stayed in Eagle Lake are unlikely to reproduce since these species require flowing water to successfully spawn (Appendix F, Section V).

Photograph VI-51. Silver Carp Avoiding Capture From the Mississippi Department of Wildlife, Fisheries and Parks Electroshocking Boat in Steele Bayou, MS

2. Post-Flood Response to Cultural Resource Issues. Prior to floodway activation in May 2011, archaeological site 23MI136 was known to be an historic Euro-American site located close to the front line levee at Birds Point. Unknown to the MVM and its archaeological contractors was the fact that this site also contained a late Mississippian component and an associated cemetery buried in a natural levee. The natural levee was incorporated into a late 19th century levee that was later incorporated into the Corps front-line levee after the 1927 flood. After the scouring of this prehistoric component during the activation of the

BPNM floodway, the remains of at least 25 men, women, and children were scattered over a seven-acre site along with temporally diagnostic artifacts. After consultation with the MO SHPO and the affiliated tribes, an expert team was assembled to collect and inventory these remains and the associated artifacts. The team included CORPS archeologists, members of the Osage Nation, and the MO SHPO staff archaeologist. In compliance with state law, the MO SHPO took custody of the human remains and later made them available for scientific analysis by the St. Louis District Mandatory Center of Expertise for Curation (MVS-MCX). The MO SHPO will be initiating Native American Graves Protection and Repatriation Act (NAGPRA) consultation for their final disposition with several culturally-affiliated tribes following this scientific analysis by the MVS-MCX. A full site investigation to determine site integrity and the National Register eligibility of the remaining site was conducted for the MVM by the MVS-MCX.

The final report of these investigations will be published in 2012. The entire archeological site was restored by filling the scour holes, and then using geotextile fabric and an additional meter of soil to prevent future exposure by levee maintenance or future inundation. To ensure no future adverse impacts from scouring, the front-line levee was realigned following the directive of the MVD Commander. A post-flood damage assessment, using LiDAR survey data of the entire BPNM Floodway identified additional scouring near several sites at the south end of O'Bryan Ridge with known archeological importance, including burial grounds and a historic post-European settlement homestead. However, further field investigations found severe scouring near these sites but no evidence that any of the major sites were damaged. No other human remains were found or have been reported by landowners to the MVM.

G. DATA INVENTORY AND MANAGEMENT

1. Introduction. During the 2011 Flood, the Corps initiated a review of its data gathering and management practices for post-flood data from a division-wide perspective. Post-flood data consists of information used in the analysis and was gathered during and immediately after the event. The review concentrated on MVM, MVK, MVN and MVD. However, the information systems that stored post-flood data from other districts (MVS, MVR) that were involved in work during the flood and in post-flood events were also reviewed. The effort focused on the gathering, storage, organization, accessibility, and preservation of post-flood data for the 2011 Flood.

To define the extent of post-flood data holdings across the division, two approaches were used: in-person interviews and demonstrations of a branch's, a section's, or an individual's post-flood data practices. These were conducted for MVM, MVK, and MVN personnel. Remote reviews of data captured in informational systems were conducted for the other districts.

The results of these activities were summarized in an Excel spreadsheet which was entitled a "data type catalog" which lists informational sets and applicable metadata. The catalog serves as a snapshot of what data was collected, what data was available, and where the information was stored following the flood event. This catalog can be accessed when analyzing the effects of the flood and has also served as a review of the data practices within MVD in relation to flood activities. The metadata presented in the catalog is described in table VI-5. While the catalog was released to the team for immediate use, due to the catalog's robustness, it served as the backbone for review and recommendations made regarding data management practices. The catalog can be found in Appendix I, *Data Management*.

Table VI-5. Metadata Fields in Data Type Catalog

Metadata Field	Description of Metadata
Data Type	Description of the data
Location	Specific geographical area described in the data, if applicable
Data Format	Software type used to display the data
Storage	General type of storage media on which the data is kept
Associated System	System in which the data resides, if applicable
Availability	How widely the data may be accessed
District (Housed)	District that hosts the data
Collected By	Which SPE team collected the data, if applicable
POC	The name of the individual responsible for the data
POC Organization	The organizational code of the individual responsible for the data
POC Contact Info	The phone number for the individual responsible for the data
Comments	Add'l information about the data added by the Data Management Team

A Preservation Plan and a Preservation Manual, both specific to the 2011 post-flood data were produced during the data management review. The Preservation Plan details methods to store the data to ensure that historic flood data will remain available for future use. The Preservation Manual is based on the Preservation Plan, but rather than focusing on the Corps as a whole, it is aimed at the District level. The manual should serve as a flood fighter's guide to ensuring the lasting accessibility and integrity of data through simplified steps and explanations on a format by format basis that can be initiated following a flood event. Both the Plan and the Manual are based on the most current best practices of the preservation and records management fields and follow all applicable Corps and DA regulations. They can be found in Appendix I, *Data Management*.

2. State of MVD's Data Immediately Following the Flood Event. During the survey of the lower three Districts, it was clear that each District had orchestrated its own data collection efforts, focusing on internal needs. These data collection efforts were narrow in scope and focused only on the data that was required by an individual office. Because the emphasis was placed on the smaller organizational elements within each district, opportunities for data interaction were limited. Details are shown in table VI-6.

TableVI-6. Causes and Related Problems with Small Unit Focus

Cause	Issues
Focus on Singular Practices	• Loss of contextual information causing reliance on institutional memory • No division enterprise focus on storage and handling practices resulting in limited access • Possible cause of duplication of work
Limiting Use	• Added cause of perishability to data • Promotes singular analysis removed from complimentary data sets

While staff generally knew who to contact regarding different data sets within their own district, the district structure limited their awareness of and access to data belonging to other districts. Individuals within management knew who their counterparts were within other districts and who at division level was responsible for the more comprehensive data sets. Individuals outside management, however, generally did not possess this knowledge. While most individuals within the division did not object to sharing data, some had not considered an immediate need to do so. These practices can lead to data gaps, which could skew analysis.

Preliminary findings also suggest that the data management and gathering practices by district personnel do not consistently incorporate the goal of a macro-analysis of river data. It appears that this view is representative of district operations and individuals were performing tasks that would normally occur after a flood event. Additionally, in many districts there was still strong support for only a district-focused report. While individual opinions are to be expected, this approach and culture, if not changed will affect the ability to produce a reliable and comprehensive data set for future events.

Observations indicate that many data storage practices have a localized focus and have a district-centered approach. Following the flood, there were no standards for data storage except for systems mandated by work processes at regional levels or higher. The major analysis tool used during flood fighting was Freeboard, which captured and housed location data regarding sand boils, sand bag placement, equipment staging, and photographs of the flood damage. This system was used by all Districts experiencing flooding. The use of Freeboard enabled post-flood data to be a completely digital collection effort.

While electronic formats can allow greater accessibility throughout the Division, storage practices among Districts vary, resulting in accessibility limitations. Table VI-7 outlines the most common storage devices used. The most prevalent storage devices were the office or district specific servers. For a complete discussion of the standards and deviations of Corps information storage systems, see Appendix I, *Data Management.*

Table VI-7. Storage Locations by Percentage

Storage Location		Usage
District Server		
ProjectWise	56.34%	76.24%
Office-Specific	30.22%	
SharePoint	12.12%	
Outlook	1.30%	
Internet (e.g. ENGLink, Facebook)		7.82%
ERDC Server		6.54%
Freeboard		4.98
Hard Drive		0.85%
CWMS		0.71%
Intranet		0.28%
Unavailable Data		2.56%

The internal safeguards and organization standards of these servers are generally focused on the individual offices housing the server within the district. As such, these servers and the data they contain are not widely known outside the organizational unit they serve. There is limited access from other offices and districts to data housed in this manner.

3. Data Risks. Current Corps data management practices frequently focus on short-term stability and access with few distinguishable efforts or established practices aimed at medium or long term preservation that keep data in a usable, preserved, and legally actionable state. The short-term stability arises from the "freshness" of the electronic data collected requiring no extra work for the data to be usable and stable. As this data ages, migration and preservation work must be performed to keep the digital information accessible for future needs. It should be noted that all levels of personnel interviewed during the survey stated they did not perform this work, but acknowledged the long-term needs of this data and the desire to have these steps completed. Figure VI-29 summarizes the data risks.

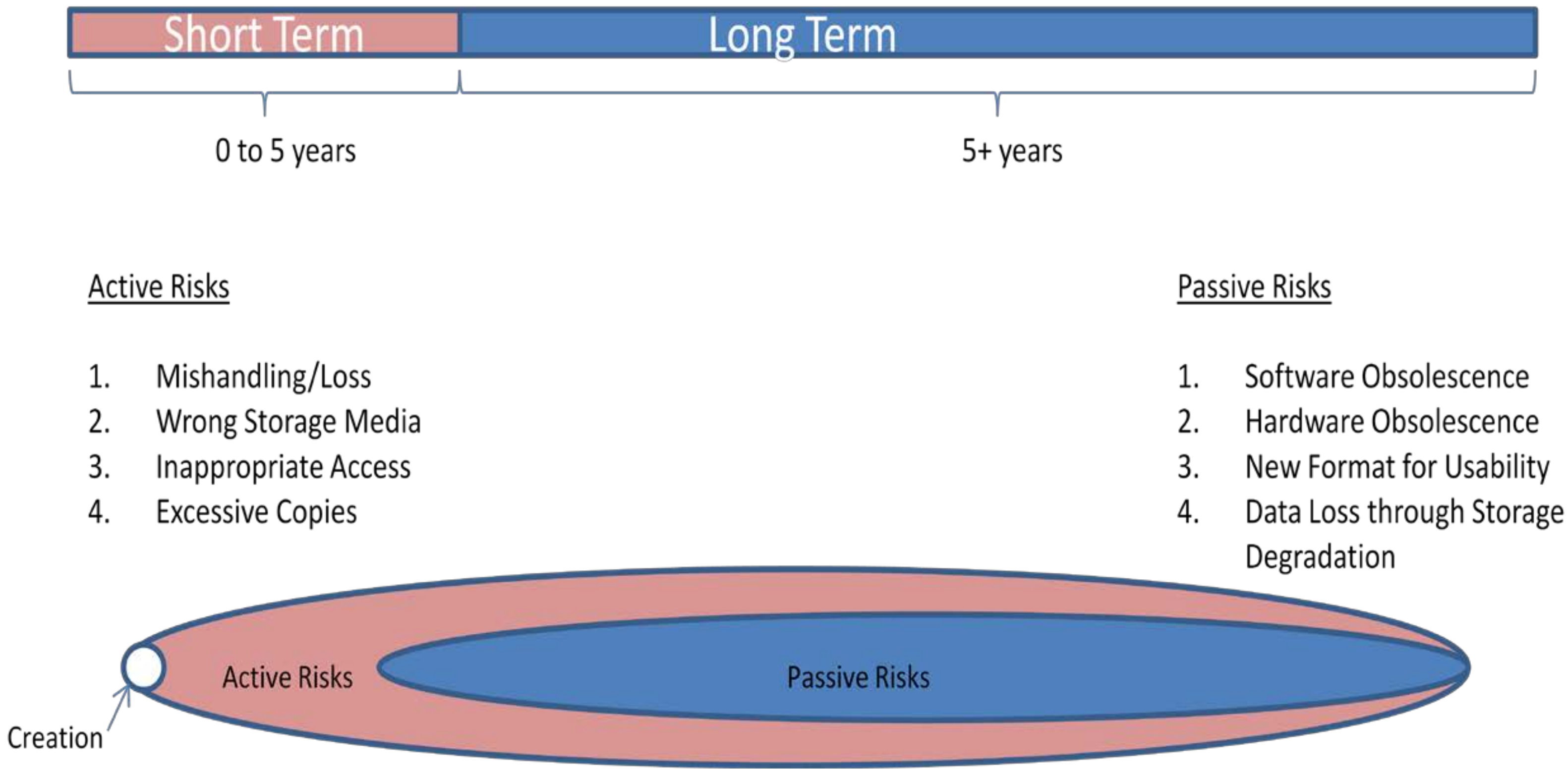


Figure VI-29. Data Risk Timeline

While there are timing, permanency, and integrity risks, there are also risks to the agency. In particular, these risks come from data provided to the public. Once information is released, the Corps' assumption has been that the public operates within the reasonable constraints associated with the information. All information collected and distributed to the public via social media during the flood fight effort represented unique risks due to the ad hoc nature of their use with no formal agency agreements. This results in the Corps being reliant on a private company to store and insure their information as the social media provider sees fit. It is in the agency's best interest to capture and preserve all such communications.

H. COMMUNICATIONS AND COLLABORATION

In an overall evaluation of how the MR&T system performed during the 2011 Flood, an evaluation of communications-related efforts was performed. The evaluation considered communications with the public, the media, non-governmental agencies (NGOs), and other Federal, state, and local agencies, as well as, internal communications between Districts and between Districts and MVD. Information related to the following activities was considered in the analysis:

- State Agency/Levee Board Meetings
  - Baton Rouge, LA, September 7, 2011
  - Pearl, MS, September 8, 2011
  - Cape Girardeau, MO, September 27, 2011
- NGO/Environmental Agency Meeting
- Navigational Meeting
- Interviews
- Public meetings
- MVD Collected AARs
- IRTF Meetings
- Press releases since the flood
- Social media use after the flood
- Developing Protocol Regarding the Release of Inundation Mapping
- Communication with internal/external stakeholders in following Structure Operations
- 2012 Flood Preparedness Workshop

The primary objectives were to determine what the Corps did wrong, what the Corps did right, what the Corps could do better, identify unresolved issues/concerns, and to generate suggestions and recommendations for future communications efforts. Several methods were used to obtain feedback and perspectives on Corps performance. These included interviews, meetings, and sharing various reports and news articles associated with the Corps and the flood. Summaries, a list of meeting attendees and transcripts of these meetings can be found in Appendix E, *Communications and Collaboration*. In addition to meetings, numerous interviews were conducted to obtain feedback from EOC representatives, Commanders, PMs, PAO, GIS, state LNOs, Area Office Commanders, AAOs, economists, USCG, levee boards, etc. Copies of the responses to interview questions are provided in Appendix E, *Communications and Collaboration*.

MVD also hosted a system preparedness workshop following the February 2012 IRTF meeting. Part of the purpose was to convey information about the status of on-going repairs and the residual risk for future flooding. Each district in MVD made presentations on the status of their flood control systems to the state and agency partners in the IRTF. This workshop included inundation maps for areas of interest throughout the valley and information on FRM measures. These efforts are expected to make stakeholders in the Mississippi Valley more aware of the residual risk following the 2011 Flood.

SECTION VII
SUMMARY AND CONCLUSIONS

A. MR&T SYSTEM PERFORMANCE/DAMAGES PREVENTED

The performance of the MR&T System during the 2011 Flood is determined by the manner in which it was operated and its physical performance. Its overall effectiveness is measured by the amount of flood damages that were prevented by the flood risk management system (FRMS), or in terms of its percent flood risk reduction. This also relates to the degree of protection afforded by the project.

Section IV described the operation and emergency activities performed during the 2011 Flood and the vulnerabilities the event revealed in system and the way it was operated. Section V described the economic and environmental impacts of the flood and the damages that the System prevented. The following paragraphs and subsections summarize the primary conclusions related to the performance of the System during the 2011 Flood. Recommendations, based on these conclusions, are identified in Section IX.

1. Operations. In general, the System was operated as it was designed to be operated, and the operational plans in place at the start of the event were utilized by decision makers. However, the magnitude of the event tested the System and its individual components like no flood before it and exposed vulnerabilities in many system components and the plans used to operate them. In some cases, operational decisions were required that deviated from pre-flood plans. Details related to those decisions are provided in Section IV and, where appropriate, recommendations for updating plans are provided in Section IX. Additional details related to lessons learned during the flood fight are provided in the After Action Reports in Appendix E, *Communications and Collaboration.*

New technologies presented opportunities to utilize several enhanced tools such as Smartphones, and social media sites (e.g., Facebook and Twitter) that were not fully considered in pre-flood plans. These tools were quickly applied and used successfully to improve internal and external communications during the flood. Properly applied, the enhanced communications tools work well. When they were not applied properly, confusion and frustration resulted and special rules for the proper use of social media were found to be needed. Some other technology related problems encountered in the field included poor cell phone reception in some remote areas, a shortage of phones and radios, difficulty in obtaining them, and the issue that too few people were trained to use some information collection and sharing tools and applications at the beginning of the event.

Overall, the operation of the System was successful and new tools were utilized extensively and effectively during the 2011 Flood. However, there is room for improvement in nearly all areas, particularly in the realm of communications. Internally, some Emergency Managers felt that they could have helped address and minimize some of the more controversial issues if they were in the field directly supporting the District Engineers during the decision making processes. Adapting the pre-flood plans to fully consider new tools and apply the lessons learned during the 2011 Flood will improve operational responses to and preparations for future flood events.

2. Damages. As discussed in Section V, the 2011 Flood affected approximately 119 counties and parishes in portions of seven states. According to damage analyses performed using the HEC-FIA model, damage impacts for the existing 2011 event (as it occurred; i.e., Scenario 1) were estimated to affect 43,358 people, 21,203 residential and nonresidential structures, and 1.2 million acres of agricultural land. Total damages are estimated to be about $2.8 billion. Estimates of the number of inundated structures, the degree of inundation, and the associated dollar damages, provide a profile of the system-wide impacts associated with a given scenario. While the aggregate system-wide estimates are constructed from estimates at the level of the individual structure, definitive attribution of a specific result to an individual structure in the form of inundation, depth of inundation, or dollar damage is not appropriate.

Both Section V of this report and Appendix G, *Economics*, provide greater detail regarding the description of damage results.

3. Results of Flood Damages Prevented. Flood damages prevented by the MR&T Project are based on the difference between the without-project conditions. Based on flood damage estimates, the MR&T System prevented approximately $234 billion in total flood damages during this single event. Without the MR&T Project, approximately 1.46 million residential and commercial structures would have been impacted. With the MR&T Project, this decreases to 21,203.

In comparison, the MR&T System (with reservoirs only, Scenario 2) prevented approximately $11.8 billion in urban and agricultural flood damages during the 2011 Flood, which results to only a 5 percent reduction in total flood damages.

4. Project Effectiveness. Project effectiveness is measured by the amount of flood risk reduced by the project, or in terms of its percent flood risk reduction (FRR). This also relates to the degree of protection (DOP) afforded by the project. The results of project effectiveness from flood damages prevented are displayed in table VII-1for each scenario. Based on the results of the flood damage evaluation, the FRR for Scenarios 1 and 4 resulted in a 98 percent DOP while Scenario 2 (reservoirs only) provided only minimal protection in terms of FRR with a 5 percent DOP.

5. Conclusion. Without the MR&T Project in place (i.e., Scenario 3) total flood damages in the seven-state impacted area would have been over $237 billion. Furthermore, with the Project, as operated during the 2011 Flood event, implementing Scenario 1—the MR&T Project (with minor deviations in the operations of the reservoirs)—provided a 98 percent flood risk reduction. .

Table VII-1. Effectiveness of MR&T Project [1]

		Without MR&T Project (Scenario 3) [2]	With-Project Conditions		
Scenario	**With-MR&T Project Description**	**Total Damages**	**Total Residual Damages**	**Total Damages Prevented Benefits**	**FRR [3]**
1	**As Occurred 2011** (minor deviations in reservoir operations)	$237,152,397,000	$2,863,843,000	$234,288,554,000	98 %
2	**With Reservoirs, But No Levees**	$237,152,397,000	$225,315,506,000	$11,836,891,000	5%
4	**As Designed 2011** (no deviations in reservoir operations in 2011)	$237,152,397,000	$2,863,843,000	$234,288,554,000	98 %

[1] values expressed in 2012 prices

[2] the without-project condition

[3] percent of FRR from project implementation; also referred to as DOP

B. DAMAGES TO THE MR&T SYSTEM

The 2011 Flood was the largest on record for the MR&T System. The MR&T System was designed to pass extreme events with limited damage to its components.

Extreme flood events affect levee systems in predictable ways. Typical problems include overtopping, breaching, erosion of the levee or batture, slope stability, and seepage issues, often resulting in soil boil formation. Damages to levees should be limited to seepage, erosion/scour, and slope protection/paving issues. Overtopping and stability issues should not occur for the PDF or lesser events. A possible exception is when the landside slope becomes saturated from long-term flood events. In addition, levee-floodwall tie-in failures should not occur in a properly designed and constructed FRM component.

Seepage is not detrimental to levee safety unless it moves material through the development of sand boils. Seapage repair measures typically include the addition of berms or relief wells. Seepage repair measures typically include the addition of berms or relief wells.

Prolonged high water and associated velocities often cause increased scour and erosion of levees. As a result, a decreased levee section can become a stability issue during periods of low water. In most cases, scour and erosion repair measures consist of slope paving and protection above the water line and the addition of articulated concrete mattresses (ACM) below the water line.

The damages and deficiencies discussed in this section are based on the 2011 DARs. These reports are summarized in Appendix B, *Levees and Floodwalls*. The performance, damages, and deficiencies identified for each Levee System are discussed by District and summarized in table VII-2.

Table VII-2. Post-Flood Levee System Acceptability Rating By District

District	Number of Systems	Number of Systems Rated Unacceptable (pre-flood)	Number of Systems Rated Unacceptable (post-flood)
MVM	7	1	4
MVK	2	2	2
MVN	6	0	0

During the 2011 Flood, nearly all of the levee/floodwall systems experienced some degree of damage. This is a deterministic indicator that the Systems were not over designed, and emphasizes the need for continued maintenance of all project features. The acceptability rating referenced in table VII-5 is based on criteria used during yearly routine inspections. An “unacceptable” rating occurs when one or more components are rated as unacceptable, preventing the segment or system from performing as designed.

The Channel Improvement Program (CIP) identified a significant number of sites that sustained damage to ACM revetment during the 2011 Flood. ACM revetment damage consisted of upper bank erosion, toe scour, and areas of failure. Of the failure sites, 44 were categorized as critical, meaning that their locations are in close proximity to the mainline levee. Continued or further ACM revetment failure at these locations could compromise the integrity of the mainline levee and navigation channel and increase the cost of repairs.

The CIP has also identified numerous locations on the Mississippi River where dikes sustained damage. The damage generally consisted of structural degradation associated with movement of riprap, flanking, blowouts, expansion of existing notches, and downstream scour of the bankline. If left unrepaired, the damage presents an increased risk to the integrity of the FRM and navigation systems and ultimately, the cost of repairs.

Based on a holistic view of the 2011 Flood and the performance of the MR&T System, the following additional conclusions may be drawn regarding the system.

- The 2011 Flood was one of the largest on record, particularly in the lower reaches of the Mississippi River.
- Although it was one of the largest floods, much of the extreme rainfall was concentrated resulting in range of interior flooding issues including drought-like conditions on the lower end of the system.
- Flood fighting was a key measure during the flood. The Corps assigned approximately 1000 staff to the flood and spent nearly $60M from March to August while Emergency Operations were underway.
- The flood fighting techniques employed at a tactical level were generally successful in maintaining the integrity of the primary FRM System. An exception is the construction of ring dikes around sand boils and seeps. Some locations reported the throat of the sand boil moving outside the ringed area and requiring re-ringing. This is typically caused by “bleed” channels located too high in the ring dike or missing entirely. The Flood Fight Manuals require updating to provide clearer instructions on ringing sand boils and overall flood fighting terminology and techniques.
- Tie-in issues (floodwall to high ground) have been studied and tested extensively in the aftermath of Hurricane Katrina, and recommendations for tie-in designs are available in the Corps Armoring Manual dated November 2011. As these recommendations are implemented, these types of problems should become less frequent.
- The operation of the MR&T System, as a whole, was adequate to minimize flood impacts. This includes the operation of gates, reservoirs, spillways, and diversions located throughout the System.
- There were 24 reservoirs utilized during the flood with only 5 of them being an MR&T component. The use of the 24 reservoirs ranged from simply monitoring conditions and reporting to normal control to deviation from normal control. Six of the reservoirs reached at least 100% of their flood control storage. Dam safety ratings of reservoirs influences their operation and could impact flood levels in the future.
- No significant breaches occurred in the primary FRM System. Minor breaches occurred in a private spur levee and as part of the operation of the New Madrid Bend Levee.
- Both MVK MR&T System segments were unacceptable (pre-flood), requiring extra diligence during 2011 flood fight operations. An "unacceptable" rating occurs when the condition of one or more components may prevent the system segment from performing as designed.
- One of seven MVM MR&T System segments was unacceptable (pre-flood). This increased to four systems post-flood.
- None of six MVN MR&T System segments were rendered unacceptable (pre or post flood).
- The system contains pre-flood deficiencies of which some were not tested by the flood and remain a risk. An example of such underlying/residual risks relates to the 11 percent of the MR&T System on-going construction efforts that may continue for decades.

C. ENVIRONMENTAL AND CULTURAL RESOURCES

The LMRV covers 36,000 square miles of diverse forest, grasslands, swamps, marshes, productive agricultural land, and some urbanized areas. It includes the Red River Basin, Yazoo River Basin, the Atchafalaya River Basin, and the Mississippi River Delta plain sub-regions. The area is rich in biological diversity and contains some of the most important areas of bottomland hardwoods, forested wetlands, and coastal wetlands in the Nation.

The 2011 Flood's effect on the environmental and cultural resources of the area was largely related to rapid and prolonged inundation of nutrient-rich freshwaters. While much of the inundation would have happened during 2011 with or without a FRMS, in some places the depth or duration of the flooding was influenced by the MR&T system. This resulted in forcing some species to relocate or to move to unsuitable locations, the loss of the young of the year in some mammalian species, the over-freshening and excess nutrients in estuarine areas, and the erosion of cultural resource sites.

Although the Mississippi alluvial plain is ecologically adapted to periodic flooding and inundation, a flood of the magnitude of the 2011 Flood stresses organisms. In addition, in some ways the engineering structures, that protect many areas, concentrate flood waters in other areas beyond what would occur naturally. While many of the effects of such an extraordinary influx of freshwater are unavoidable, there may be a few opportunities to modify operations to minimize environmental and cultural resource damages while still providing a high level of FRM. Section IX includes many recommendations for future efforts and further studies. Perhaps the most underappreciated impact of the operation of the flood control system is the impact on the estuarine system and the oyster industry in Mississippi Sound, Lake Borgne, and Breton Sound, LA. It was estimated that the economic losses to the oyster industry in Mississippi alone in 2011 were approximately $60 million dollars (Appendix F, Section VI). There is also new evidence (Gundersen et al. 2012) that suggests that the nutrient rich river waters may be exacerbating hypoxic areas east of the Mississippi River. Traditionally, routing freshwater floodwaters into Lake Pontchartrain was perceived as the least damaging alternative; perhaps this new information indicates that the Corps should re-examine the order of operation or the extent of operation of various components of the flood control system.

The Flood of 2011 occurred just 3 years after the previous 2008 opening of the Bonnet Carre Spillway, providing a unique opportunity to convene an environmental interagency team in 2011 that was largely composed of the same people who participated in the 2008 event. The dynamics in 2011 were much better, generating many recommendations for codifying the interagency process for future generations. Additionally, the scouring of cultural resources sites in the BPNM Floodway underscores the importance of early coordination with cultural resources personnel.

D. REPAIRS AND MEASURES FOR THE MR&T SYSTEM

The MR&T System experienced a wide range of levee-related issues from slope instability to seepage and sand boils due to the 2011 Flood. Resulting structural damages were assessed by teams who prepared documents identifying the location, nature, and extent of damages. The teams also identified appropriate repair alternatives and estimated preliminary repair costs. Theses assessments utilized a DAR format to keep the data gathering and supporting information consistent. Forty-four separate DARs were developed to ensure that all levee reaches, structures and navigational river miles affected by this event were inspected and thoroughly documented. Through the assessment effort a FRAGO critical repair classification system was used to classify the degree of risk and consequences associated with each of the damaged areas. Using this classification system, MR&T repair projects were classified as either "critical" or "non-critical" and appropriately sequenced for construction.

During the 2011 Flood, nearly all of the levee/floodwall systems experienced some degree of damage. Repair efforts are moving forward and include seepage repair measures such as berms or relief wells. Scour and erosion repair measures are another common type of repair effort being advanced and these primarily consist of slope paving and protection above the water line and the addition of (ACM) below the water line. Repairs to the BPNM mainline levees are also proceeding and include restoration of the fuseplug levee components.

Damages to the MR&T floodways as a result of the 2011 Flood primarily consisted of scour below spillways, sedimentation in inflow and outflow channels, wave wash erosion, and loss of some monitoring equipment. Scoured areas are being repaired through appropriate techniques of filling and compaction. Sedimentation and wave wash erosion areas are also being addressed to restore areas to pre-flood conditions and assure the proper operation of the floodways in the future.

During the Flood, many Mississippi River basin reservoirs were utilized to attenuate the flood crests and reduce overall impacts. The only MR&T reservoir that experienced flood damages was Wappapello Lake. Repairs are moving forward on the damaged reservoir features including the exit channel, spillway, roads, and utilities. Currently the overall project is still able to function as intended and is not in danger of failing.

The channel improvement program (CIP) has identified a significant number of sites that sustained damage to ACM revetment during the 2011 Flood. Revetment damage consists of upper bank erosion, toe scour and areas of ACM failure. Repairs consist of restoring the bank to the previous configuration, adding a layer of ACM to an existing revetment, replacing damaged revetment and restoring upper bank paving to the previous configuration. Continued or further revetment failure at these locations could result in a threat to the integrity of the mainline levee and navigation channel and increased cost of repairs.

The CIP has also identified numerous locations on the Mississippi River where dikes sustained damage. This damage consists of removal of riprap, flanking, blowouts, expansion of existing notches, downstream scour pockets in the bankline and overall structure degradation. Repairs consist of restoring the damaged dikes to the pre-flood configuration, in most cases. Consideration is being given to leaving a notch in damaged sections of some dikes to capture environmental benefits when it does not compromise the structure or its performance. If left unrepaired, this damage will progress over time, presenting an increased threat to the integrity of the FRMS and navigation systems and increased cost of repairs.

E. RECOVERY STRATEGY AND TIMELINE

The MR&T System recovery effort is moving forward through a combination of immediate, critical, and non-critical repair projects to fully restore the System to pre-2011 Flood conditions. These projects include repairs to Mississippi River levees, channel structures, shoaled areas, floodways, and other flood damage reduction structures located throughout the river valley. The MR&T recovery strategy is focused on repairing critical high risk damages first. After these damages are addressed, work will then shift to less critical items and proceed until the MR&T System is fully restored back to pre-2011 Flood conditions. As work moves forward, the Corps will also seek to maintain a balance of system risks and not cause undue risks to individual damaged areas within the MR&T.

"Immediate Need Repairs" were self-funded and initiated and late 2011 to address 29 high risk damaged areas within the valley at a cost of $170 million. After passage of the Consolidated Appropriations Act in December 2011 which provided $802 million in supplemental funding for the MR&T repairs and receipt of additional funding from two other sources ($35 million FCCE, and $153 million Operation & Maintenance), the Corps was able to proceed with implementing 118 "Critical Repair" projects needed to restore and prepare the System for the next high water event. The supplemental funding would also fund just over 100 of the 302 "Non-Critical Repair" projects that were identified and ranked through the MR&T damage assessment process. Completion of these repair efforts will reduce the current elevated flood risks to the System and restore the MR&T to pre-2011 Flood conditions. The remaining "Non-Critical Repair" projects will be addressed as funds from the annual O&M budget allow.

MR&T repair projects are moving forward, and most of these efforts will be completed in 2012 and 2013 (figure VII-1). Completion of several "Critical Repair" projects will extend into later years (i.e., 9 in 2015 and 1 in 2016) primarily due to the magnitude of the required repairs and duration of the construction efforts. Approximately 25 of the "Non-Critical" repairs were not scheduled at the time of this writing and therefore are not included in figure VII-1.

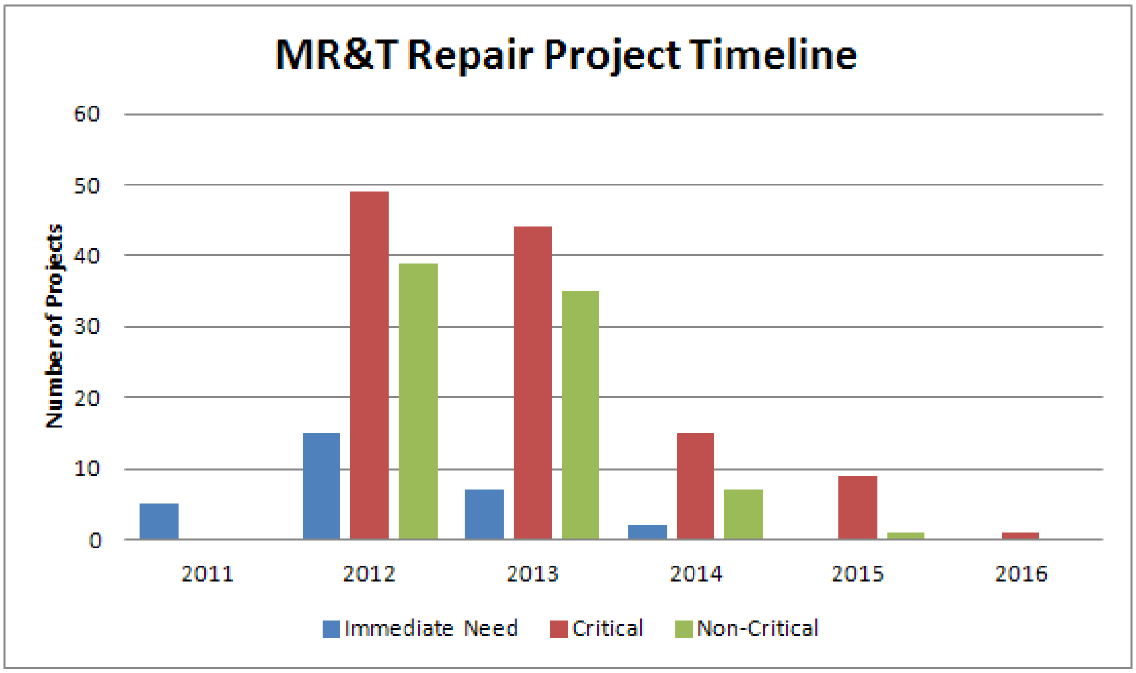


Figure VII-1. Timeline of MR&T Repair Project Completion

The strategy and timeline of MR&T repairs may change as a result of the lessons learned and the recommendations captured through this post-flood effort. Additional studies are also underway that may further improve repair efforts and modify construction schedules. Restoration of the MR&T System will continue with a focus on timely and informed progress towards completion.

F. IMPACTS OF CONSTRAINTS

The damages to the MR&T System will be repaired and the deficiencies and vulnerabilities in its flood fight plans will be addressed as MVD recovers the System. The System will be restored to a pre-flood condition and in some cases be a better system. A challenge such as the 2011 Flood reveals strengths and more importantly weaknesses of designs, construction, plans and processes. For example, the flood confirmed that underseepage is a major issue and will impact the plans for completion of MR&T levee construction. The restored system will undoubtedly be stronger after all issues are addressed through recovery; however, there are constraints that preclude the execution of a perfectly efficient and timely construction project. Such constraints are common in Corps projects and include real estate actions, funding limitations, borrow pit acquisitions, land acquisition, environmental/cultural mitigation, design time, stakeholder/partner engagement, etc. Although these constraints are shared with many Corps' projects, the MR&T System was damaged to the extent that it presented unacceptable levels of risks to lives and livelihoods that rely on the FRMS.

Prior to the passage of the Consolidated Appropriations Act 2012, PL 112-74 (December 2011), the Corps recognized the urgency to self fund 29 projects in high risk areas within the valley at cost of about $170 million. The severity of damages and associated risks the 29 areas posed made them a priority for the Corps to quickly accomplish the repairs by pulling funding from other ongoing Corps projects from across the Nation.

The process of prioritization and self funding proved to be very difficult, and inefficient. Identifying where to draw the line for these initial projects required balancing the severity the life safety risks with the level of funding that could be found within the Corps' budgets. A significant effort was invested in explaining to stakeholders and the public why certain projects were funded and others would be put on hold until funding was available. The process of identifying and pulling existing Corps funding from other Districts throughout the country was also difficult. Evaluating the financial status of thousands of projects required a significant effort. This process was made even more difficult because transferring funds from other Corps projects caused work stoppages and completion delays (requiring communication of these impacts with cost-share partners and stakeholders) and other inefficiencies. No time frame could be provided as to when or even if the funds would be returned to those projects.

The passage of the Consolidated Appropriations Act 2012, PL 112-74 provided $802 million in supplemental funding to be used towards MR&T repairs. This funding along with funding from other sources ($170 million self-financed, $35 million FCCE, and $153 million Operation & Maintenance) allowed for completion of all MR&T critical repairs as quickly as possible within the constraints explained above. Project management will be monitoring construction projects for key schedule drivers and other project delivery issues. Information related to residual risk from unfinished repairs will be shared with internal and external emergency managers to better inform flood fight teams and river communities as they prepare for future flood seasons.

G. RESIDUAL RISKS

The MR&T System will not be without risk after all repairs of 2011 damages are complete. Many of these residual risks relate to the 11 percent of the MR&T System that is not yet complete due to on-going construction efforts that may continue for decades. The incomplete portions of the MR&T System increase the chances of overtopping as well as underseepage-driven stability problems. Pre-flood deficiencies on 3.1 miles of floodwalls on the lower Atchafalaya present risks until they are addressed since they are not planned to be repaired as part of the 2011 flood repairs. Risks will also remain in the MR&T System due to the inability to address channel improvement needs over the next several years while 2011 damage repairs continue. The channel improvement flood-related repair construction is primarily accomplished by mat laying crew and equipment. This unique resource dedicated to flood-related repairs will likely be unable to accomplish baseline channel improvement construction projects/tasks during the period of repair. The assignment of unique resources to flood repairs potentially leaves baseline work untouched, thus allowing these residual risks to remain in the System. Another example of residual and increasing risk is development in floodway lands, which increase the economic consequences of the risk equation. These residual risks can be incrementally addressed through continued funding, design, and management of the MR&T System. Effective communication, awareness, and planning will be key to best managing the MR&T System residual risks in the future.

SECTION VIII

INTERAGENCY RECOVERY TASK FORCE

A. INTERAGENCY RECOVERY TASK FORCE - OVERVIEW

In the midst of one of the most historic floods in the modern history of the Mississippi River, the MVD was charged to assemble key Federal and state agencies in the form of an Interagency Recovery Task Force (IRTF). The primary intent of this task force was to focus regional managers, leaders and decision maker's attention, priorities and resources on the challenging flood recovery. This task force met regularly for more than a year to identify and successfully address numerous flood recovery challenges and issues. An Annual Report was developed to provide a synopsis of the IRTF's activities, accomplishments and lessons learned. The Report reviews IRTF efforts in context of established purpose, mission, goals and objectives. Brief summations of the series of eight IRTF meetings convened provide understanding of the range of topics and issues embraced by this group. Products directly or indirectly influenced by the IRTF are detailed in this document as well. This Report concludes with sections on lessons learned and next steps that describe the value-added nature of interagency collaboration and its importance for continued improvement and implementation of a successful and shared responsibility for FRM.

The IRTF was conducted under the direct leadership of MVD Commanders MG Michael Walsh from May to October 2011 and MG John Peabody from October 2011 to present. This forum was designed and implemented in an integrated, collaborative, and holistic fashion to facilitate the recovery and rehabilitation of flood risk management (FRM), navigation, and floodplain management systems (FRMS) damaged by the historic Mississippi River Basin flooding of 2011. Members united in common purpose to leverage State/Federal resources and communication networks to ensure the continued safety and protection of lives and livelihoods of affected U.S. citizens, communities and industry. Charter members included regional and state-level representatives from Missouri, Illinois, Tennessee, Kentucky, Arkansas, Mississippi and Louisiana. Coordinating agencies included FEMA; NWS; USDA; USEPA; USGS; USCG; Maritime Administration (MARAD); and the Corps' Major Subordinate Commands, comprised of MVD; LRD; and Northwestern Division; and support from Southwest Division and South Atlantic Division.

The efforts by the IRTF in 2011-2012 have served to improve working relationships, increase flood risk understanding and implement critical flood repairs and preparedness actions. Group discussion covered a broad and challenging array of tactical and strategic Flood Risk/Recovery responsibilities and challenges. Member agencies leveraged authorities, experience, and resources to put the region on an aggressive and attainable path to recovery; increased flood risk awareness; and made recommendations for future flood preparedness. The regularity and focus of IRTF meetings and interactions were appropriately paced with the tempo and challenges of the recovery process. With the late December 2011 passage of and supplemental appropriations provided by the Disaster Relief Appropriations Act, the Corps is well positioned to repair and restore the majority of damaged levees, structures and navigation channels over next 2 years. With construction repairs in full swing and a below average spring flood season in 2012, the IRTF is downshifting to a long-term sustainment mode that will seek to maintain periodic interaction to ensure recovery is progressing smoothly and the working relationship among State/Federal agencies is maintained through the full life cycle of regional FRM.

B. INTERAGENCY COLLABORATION

1. Purpose. The IRTF was intended to create an integrated and holistic method of rehabilitating our flood risk management systems damaged by recent flood events, by collaborating and combining solutions for short- and long-term restoration efforts. The Task Force was established with lead Federal agencies and state- appointed members involved in assessing, documenting, and repairing FRM, floodplain management, and watershed management systems.

2. Mission Statement. The IRTF collaborative process will:

- create a multi-agency forum to solve the many regional issues and challenges that will be presented in the recovery from this historic flood event;
- provide safety and security for citizens lives and livelihoods;
- create strong regional effort to inspect, review, reset and restore our FRMS;
- pursue all potential funding methods from Federal and state sources;
- give consideration to traditional and non-traditional alternatives in repair and restoration;
- implement a collaborative and communicative approach across regional and state boundaries to prioritize our efforts and resources during the challenging recovery process;
- facilitate strategic, integrated life-cycle mitigation actions to reduce the threat, vulnerability and consequences of flooding in the Mississippi River Valley;
- create or supplement a mechanism to collaboratively solve issues and implement or recommend solutions; and
- increase and improve flood risk communication and outreach.

3. Goals and Objectives

- Implement a consistent approach across region and state boundaries in order to prioritize agencies, authorities, and resources in the rehabilitation process
- Create a strong team to inspect, review, repair and restore our FRMS and adjacent project.
- Create an IRTF management plan
- Share responsibility for all flood plain management restoration initiatives, programs, and projects in order to reduce flood risks long term
- Supply an effective outreach program to communicate short and long term to the public, as well as, educate on the agencies' responsibilities, programs and authorities
- Pursue all potential funding methods from Federal and state resources
- Ensure continuous pre- and post-disaster collaboration
- Give consideration to all structural and non-structural alternatives in repair and restoration
- Learn about programs, identifying limitations and opportunities, and combine programs to create integrated, comprehensive and sustainable solutions
- Create a multi-agency technical resource for state and local agencies
- Improve flood risk outreach by presenting a unified interagency message to better educate and advise mutual customers as a result of gaining familiarity with each agency's missions, processes and programs
- Improve internal and external risk communication, including increased awareness of residual risk
- Identify and facilitate improvements to existing programs, policies and processes

- Identify other collaboration opportunities to combine resources and identify gaps, minimize duplication of effort, and ensure consistency
- Catalog and share information on past and future projects and initiatives
- Prioritize current and future initiatives individually and collectively

4. Management Plan. The IRTF Management Plan (IRTFMP) was developed to cover the scope of the short-term efforts required for recovery from the Mississippi River Basin Flood Event. The operational boundary and the duration of the IRTF were further defined by the Commander, MVD in his request to activate the IRTF. This IRTFMP will remain in effect for the duration of the Task Force, as agreed to by its member agencies. This plan was not intended to usurp any authorities and programs currently assigned to its member states and agencies, nor deny any applying party access to existing programs for repairs and associated restoration and/or other impediments.

5. Charter. A Charter was also established and signed by participating agencies as solidarity and clarity of purpose. The paragraph on the signatory page reads as follows:

> *The Interagency Recovery Task Force was established to create a highly communicative and collaborative forum of state and Federal agencies with common interests and authorities to affect the repair, recovery and evaluation necessitated by the historic 2011 Mississippi River flood event. The signatory state and Federal agencies will consider a wide range of traditional and innovative options to develop meaningful solutions for short and long-term restoration efforts. The following state and Federal representatives are committed to working together to effectively and efficiently serve the American public and private interests for the protection of human life/safety and economic prosperity:*

The team was purposefully assembled to be strictly intergovernmental and multiple state in nature. Participating agency representatives, listed in Section VIII. A, paragraph 2, contributed a broad range of relevant and crucial experience and information to this team effort. The Corps maintained and distributed a contact database and was responsible for organizing, coordinating and facilitating team meetings, as well as recording and maintaining final meeting minutes.

C. TASK FORCE ACTIONS

Between May 28, 2011 and June 30, 2012, the IRTF held eight meetings at various locations throughout the Mississippi Valley. The first and last two meetings in this time period were conducted as webinars while the other five were one-day face-to-face meetings. Meeting agendas, presentations, and handouts are available on the Corps Regional Flood Risk Management Website (http://www.mvd.usace.army.mil/). Appendix J, *IRTF Annual Report (2011-12,)* provides a more detailed synopsis of the IRTF meetings, products, and actions. The remainder of this section provides a brief description and illustration of some of the highlighted IRTF 2011-12 actions.

1. Newsletters. A series of six IRTF newsletters and three quarterly '*Our Mississippi*' newsletters were produced over the course of the past year. These newsletters served as important communication tools which quickly and effectively informed State and Federal partners, stakeholders, members of Congress, and the general public about the continued efforts and progress of 2011 flood recovery efforts.

The IRTF newsletters provided the Corps and our partners a vehicle to communicate the flood recovery efforts through a series of pictures and articles which captured the focus of discussions, topics of concern;

and status of ongoing recovery efforts during the first year of post-flood recovery. The IRTF newsletters were distributed electronically to a large email distribution and posted to the RFRM website for direct public access.

The '*Our Mississippi*' newsletters were also produced with a number of Mississippi River Basin flood recovery and public interest stories. The newsletters were originally designed as a Corps communication tool for the Upper Mississippi River with the intent that someday the publication could be expanded to a publication for the entire Mississippi River Basin. The 2011 Flood Event was a watershed-focused response and recovery effort and offered opportunity to expand the focus and distribution of this regional newsletter. Beginning with the fall 2011 edition, all subsequent quarterly publications have continued to both provide a diverse range of Mississippi River stories of interest and to serve as a communication tool for the 2011 Flood recovery efforts. The '*Our Mississippi*' newsletter is distributed to 50,000+ subscribers throughout the Nation and reaches additional readership through electronic distributions and the '*Our Mississippi*' website.

Together the IRTF and '*Our Mississippi*' newsletters were effective communication and educational tools which provided the Corps and our key partners the ability to reach out to various target audiences simultaneously. There has been an overwhelming response of compliments and letters of appreciation from those receiving these newsletters, which speaks highly to the success of these two newsletters.

2. 2012 Flood Preparedness. A significant milestone for the IRTF and State/Federal Emergency Flood Responders was the Regional Flood Risk Management Workshop –"2012 Flood Preparedness"—held in Memphis, TN on February 23, 2012. This workshop was the idea of the IRTF and brought together a group of over 80 State/Federal agency representatives for a day-long series of presentations and discussions. Taking into account the vulnerable condition of the MR&T project and projected National Weather Service Spring forecast, the Corps mobilized a Regional 2012 Flood Preparedness Team in mid December 2011 to develop plans to manage, mitigate and communicate flood risks throughout the MR&T system for the coming flood season. This regional effort was focused on three primary endeavors: identify key risks within the MR&T, ways to minimize risk, and effectively communicate this information to partners, stakeholders and the public. The February 23 interagency workshop served to carefully coordinate, refine and communicate this team's findings, tools and recommendations across the broad array of those public officials with shared responsibility for the protection of the lives and livelihoods from flooding events. The majority of the presentations, tools, brochures and products produced during this four month effort are currently accessible on the RFRM website under "Flood Preparedness".

A 2012 Flood Preparedness Summary Report provided a comprehensive narrative of this collaborative effort. This document was developed to capture, in general terms, the efforts the MVD and partner agencies have undertaken to manage and mitigate risks associated with the great flood of 2011 and in preparation for the next flood event. It is intended to be used a tool and in conjunction with other products produced under OW-R in an effort to communicate both internally and externally the risks which remain to the public in the wake of one on the largest flood events on record.

Many tables have been provided within the Flood Preparedness Report in an effort to summarize and index information that the reader can easily reference and utilize in conjunction with other tools such as CorpsMap. Each damaged site included in this document has undergone extensive investigation and validation by experienced Corps personnel. The damages incurred during the great flood of 2011 includes nearly 2 billion dollars worth of damages to critical infrastructure necessary to the flood risk management and navigation systems benefiting both the Nation's population and economy. Further site specific detailed information is publicly available via the Regional Flood Risk Management and CorpsMap websites (http://www.mvd.usace.army.mil/) and other products such as Information Papers, Risk Management Papers, and Construction Fact Sheets.

3. Videos. Two OW-R educational videos were produced during the past year. The first, "*2011 Flood Fight*," premiered at the first IRTF face-to-face meeting in Memphis, TN in late June 2011. The second, "*Flood Preparedness and Recovery Efforts*," was released to IRTF members in April 2012. Both of these videos were posted to YouTube and the Corps Facebook page for unlimited public access and distribution. These videos have been used in a number of National meetings and congressional briefings.

4. Website. IRTF members also influenced the creation and refinement of a Regional Flood Risk Management website (http://www.mvd.usace.army.mil/) designed to improve communication, education and access to a diverse array of Flood Risk information/resources. The RFRM website has become a central repository and link to district, regional and National FRM related resources and documents. The website was especially useful in making the many IRTF meeting presentations/minutes and products readily accessible to members and interested stakeholders. The use of social media as a RFRM communication tool has continued to grow and is directly linked through the website. We expect the MVD RFRM website will continue to evolve to better meet the informational needs of our partners, stakeholders and public.

5. CorpsMap. CorpsMap is a geospatial web platform that until recently was available as an internal Corps system only. The MVD GIS cadre worked with both a regional OW-R management team and the National GIS team to establish one of the first External CorpsMap sites: http://www.mvd.usace.army.mil/. Table VIII-1 provides a rough outline of some of the key products currently being served via CorpsMap, along with a brief purpose and an anticipated update schedule.

Table VIII-1. CorpsMap Publically Accessible Products

Product	Purpose	Updated
Project Information Paper	provide general background on flood damages, potential consequences, repair options, and tentative schedule	Annually by District PM/PDT
Project Risk Management Paper	describe how risks at damaged locations are being addressed through construction, interim measures, and flood fight preparation	Biannually by District PM/PDT, Construction Rep and RCO
Project Construction Fact Sheet	provide monthly status of ongoing construction activity, key milestones, % completion, and project challenges	Monthly by PM/PDT and Construction Rep

6. Regional Communication Plan. IRTF member input was sought in the development of a Regional Communication Plan designed to provide structure and guidance regarding OW-R communications with partners, stakeholders, and the public. By carefully orchestrating notifications to the media and key interests regarding the status and outlook of flood damages, the Corps and partner agencies facilitated awareness of public safety, flood recovery and flood preparedness. Key messaging is focused on damages and vulnerabilities; reliability of MR&T; near-term risk management; and the shared responsibility of flood response, mitigation and risk management. Effectively communicating the coordinated flood recovery efforts among the Federal, local and State governments were designed to reduce public anxiety and promote confidence in the dedicated, purposeful and collaborative approach government agencies are taking in to reestablish the full integrity of their flood control and navigation systems. There are three major parts to this Communication Plan:

1. Introduction - includes principles of open and transparent communication, goals and objectives, background, audience and timeline
2. Communication Strategy - identifies tools, methods, resources and protocols for communicating OW-R information methodology
3. Key Messaging - includes important facts/figures, talking points and "bridging messages"

The Regional Communication Strategy serves as a framework and guidance for both the internal and external transfer of OW-R information via CorpsMap, fact sheets, talking points, presentations, press releases, social media, and website. It will also highlight some of the key participants and groups with whom regular communication is required (e.g. stakeholders, levee districts, congressional, IRTF, State emergency managers, etc). It is important that this shared responsibility be well coordinated and controlled to ensure our communications are responsive, purposeful, and consistent. Research from past hurricane and flood disasters in 2008 and 2009 taught the Corps to better communicate safety information, flood risk management strategies, and recovery assistance to the public. Based on those lessons learned, the goal is to proactively connect stakeholders and the public with fact-based and timely information, and reaching a diverse target audience: partners, stakeholders, agencies, businesses, local communities. Natural disasters cannot be specifically planned for; however, communication tools that will continue to be updated can be put into place

7. Post-Flood Reports. Although several of the member agencies have recently completed Post-flood reports and are still developing such reports. While the IRTF meetings have had presentations on these evaluative reports, the reports themselves have largely remained internal to the respective state or Federal agency. Upon review and approval, these reports will be made available to fellow partners and the public.

D. PARTNER PERSPECTIVES AND LESSONS LEARNED

The efforts by the IRTF in 2011 to 2012 have served to improve working relationships, increase flood risk understanding and implement critical flood preparedness actions. Group discussion covered a broad and challenging array of tactical and strategic Flood Risk/Recovery responsibilities and challenges. Member agencies leveraged authorities, experience and resources to put the region on an aggressive and attainable path to recovery, increased flood risk awareness and recommendations for future flood preparedness. The regularity and focus of IRTF meetings and interactions were appropriately paced with the tempo and challenges of the recovery process.

A great deal was learned from the 2011 flood season, particularly in the areas most damaged by the flood. That knowledge is being applied to both Federal, state and local recovery efforts to ensure timely restoration of FRM and navigation systems. Effective FRM requires the integration of mitigation planning, preparedness, response, and recovery programs and activities into a coordinated FRM "life-cycle" framework. The conceptual framework for implementing the FRM program is focused on ensuring programs and authorities of Federal, state, local, and tribal partners are coordinated and synchronized so that the combined actions achieve effective management of the flood risk. The Corps is a key contributor in "driving down" the Nation's flood risks through its programs to

1. plan structural and nonstructural projects to manage flood risks;
2. inspect the condition of existing FRM infrastructure;
3. provide technical and planning support to states and communities;
4. conduct emergency measures to alleviate flooding consequences; and
5. rehabilitate levees and other FRM infrastructure damaged by flooding.

It is important to bear in mind that responsibility of managing the Nation's flood risks does not lie exclusively with the Corps or any other single Federal or non-Federal entity. Rather, responsibility is shared across multiple Federal, state, and local government agencies, with a complex set of programs and authorities, and private citizen choices/actions.

In May 2012, IRTF members were presented with three "Lessons Learned" oriented questions as means to record their feedback on the May 2011 through May 2012 IRTF experience. Responses to these questions were submitted in writing and provided verbally during the July 14, 2012 teleconference. Responses to the three questions have been summarized without attribution to individuals or agencies. The following views/quotes emphasize many of the key lessons learned as expressed by individual representatives.

Did the IRTF experience provide added value to your State or Federal agency and our shared public/stakeholders?

Overwhelming positive response from IRTF members indicated the experience was very beneficial and "value-added." Many members provided specific examples of how they were able to beneficially use the information provided during the regular meetings. A brief listing of some of the examples provided by members included: synchronization of repairs; leveraging resources and expertise; identification of common risks/uncertainties; helped focus coordination/response; allowed direct linkage to other affiliations or endeavors; kept respective key leaders well informed; better understanding/appreciation for MR&T system; development of new communication and forecasting tools; understanding of complexities and challenges of repair effort; platform to discuss state perspectives and priorities; common vision and purpose; set an important precedent and model for interagency collaboration; learned a great deal about member agencies.

What improvements or enhancements to the IRTF concept would you recommend?

Recommendations included the following: conduct equitable balance of webinar and face-to-face meetings; need to have better state representation and participation; annual workshop excellent idea; incorporate more mitigation alternatives into discussions; working groups could help focus certain issues/challenges; would be good to expand topics of discussion and incorporate natural disaster simulation exercises; watershed planning efforts would benefit from an IRTF approach.

What are the top flood risk management challenges facing our region/nation today?

This question provided a number of insightful observations and responses from the members. Topping the list of most common responses were: flood risk awareness/education/communication; aging FRM infrastructure; and Federal/State funding levels. Also included in response were the following in no particular order: timely natural disaster recovery; standard protocols for flood inundation mapping and availability; routine FRM interagency workshops or exercises; relevant/understandable stream stage/streamflow data; unified approach to FRM preparation/mitigation; interagency collaboration; stalled out watershed planning efforts.

In summary, the following selection of views/quotes expressed by IRTF members capture some of the individual or collective Lessons Learned on a variety of topics/issues brought into the IRTF forum:

"The IRTF has provided tremendous education and serves as an excellent model for value-added interagency collaboration, it is one we should do all we can to emulate and keep going."

"It is unfortunate that it has taken a natural disaster to bring us all together in such a collaborative fashion, we should have been doing this years ago!"

"The effort and information exchange that has gone into these IRTF meetings have been very impressive and educational."

"It has been particularly useful for me to hear the many state/federal perspectives on so many important interrelated issues."

"The experiences shared at the meetings helped me see how each agency was connected (and sometimes disconnected) to and from the flood response and recovery process."

"The IRTF process allowed the states to remain informed on the status of impacts and recovery efforts and provided a platform to discuss state perspectives and priorities."

"The CorpsMap and NWS extended 28-d forecasts are two products that would likely not have come about, or been shared as extensively, without the IRTF discussion and dialogue."

"The experience of the 2011 Flood and IRTF have really opened a number of eyes to the importance and value of an integrated systems approach and interagency collaboration to successful Flood Risk Management"

Given the very positive and reinforcing feedback from member agencies it was agreed that the IRTF should not immediately disband while the challenging recovery process continues. Many expressed strong support for the continued evolution of this model forum for interagency collaboration that can facilitate meeting our shared responsibility in all aspects of the FRM life cycle and possibly other regional issues as well. An important and recurring comment during the IRTF lessons learned discussion was that the IRTF concept should serve as a model for a number of other challenging regional issues that also have shared responsibility across multiple Federal and state agencies. It is expected that the local, regional, state, and Federal members of the IRTF will continue to provide safety, security, and quality-of-life measures to American citizens and industry.

SECTION IX
RECOMMENDATIONS

In developing this report, opportunities to better restore, sustain, and improve the MR&T System have been identified through the systematic assessment of its operational and structural performance during the 2011 Flood. This section provides both overarching recommendations and specific component team preliminary recommendations that should be seriously considered to address the System's immediate and future needs and vulnerabilities. The recommendations also identify opportunities that should be further analyzed to improve current MR&T processes and component functionality. Additional assessment, coordination, and potential combining of these recommendations will be necessary to advance them towards implementation.

Overarching MR&T System Recommendations

The PFR regional management team carefully considered the comprehensive listing of component team recommendations to identify key overarching recommendations for the MR&T System. These overarching recommendations capture the main themes of the many detailed recommendations developed through this effort:

- **Use the information from the PFR effort to inform repair of the MR&T System**
  Use 2011 MR&T System performance, damage, and risk assessment information developed through the PFR and other efforts to help establish appropriate repair processes. This includes efforts focused on improving levee resiliency, confirming level of protection, sharing best practices, and developing system repair plans using risk-informed decision making.

- **Use the information from the PFR effort to inform completion of the MR&T System**
  Information from the PFR effort should be used to aid in the development of a plan to complete the remaining 11 percent of the MR&T System not yet constructed. Information that would provide insights into this include MR&T performance, changing river hydraulics, improved levee engineering, economics and associated risks, environmental and other stakeholder considerations.

- **Update Operation Plans/Manuals, Communications Plans, and SOPs using information from this PFR, external inputs, AARs, etc.**
  Use information developed through the PFR effort, AARs, external inputs, and further studies to inform the update and enhancement of MR&T operation and flood fight plans/manuals, SOPs and regionally standardized communication plans. These efforts would focus on improving both internal and external MR&T related operations during major flood events and would involve refinement of existing processes and utilization of new technologies. Example efforts may include enhancing flood fight operations with newly developed tools and examining the potential need to update operations plans for key MR&T flood risk management structures.

- **Regionally standardize communication approaches and products with MR&T System floodway and backwater area stakeholders**
  Use feedback from stakeholders, lessons learned, best practices, and new technologies to develop regionally consistent communication approaches, tools and products to improve understanding, reduce impacts and improve collaboration during future floods. The IRTF offers great potential to make this a coordinated multi-agency effort.

- **Evaluate the need to conduct an updated flow line study for the MR&T System**
  Use 2011 hydraulic flood data and associated MR&T component performance to evaluate the need for an updated flow line study for the MR&T System. Physical and hydraulic changes in the river system and complex flow patterns at Morganza, Bonnet Carre, and ORCC should be examined to determine if a change in flow line data or water control plans is warranted.

- **Coordinate a regional "triage" effort to prioritize, refine and implement the recommendations identified in the MR&T System Post Flood Report**
  The next steps in advancing the preliminary MR&T recommendations in this report will utilize the existing regional program management structure and process to further screen, combine, prioritize, refine, and develop detailed scopes for recommendation implementation. This process is vitally important due to the need to establish coordinated MR&T improvement, regional priorities, and because there is limited funding available to accomplish these tasks.

These overarching recommendations are considered of significant importance as they would provide for structural/operational strengthening and benefit to the existing flood risk management system and improved efficiency and effectiveness in implementation of future MR&T construction and maintenance efforts. Many of the component team recommendations detailed in the remainder of this section would be nested within these overarching recommendations.

Recommendations with the greatest potential to improve the performance of the MR&T System components were identified and prioritized by each of the multi-District component teams working on the Post-Flood Report. These recommendations will require further refinement, scoping, and regional coordination prior to their implementation. The following sub-sections provide further description and justification of each component teams' prioritized recommendations:

A. Emergency Operations Plans
B. Reservoirs and Forecasting
C. Levees and Floodwalls Systems
D. Floodways
E. Backwaters
F. Interior Drainage
G. Channel Improvements
H. Channel Capacity
I. Environmental and Cultural Resources
J. Data Inventory and Management
K. Communications and Collaboration

The component team recommendations were further categorized as technical, operational, or strategic to help establish the most appropriate approach to advancing them. Technical recommendations (e.g., modify the design of a levee) will be evaluated, further refined and moved forward primarily by engineers and MR&T component experts. Operational recommendations (e.g., change operating plan) will be examined and implemented by MR&T component experts, managers/operators, flood fighters, and decisions makers. Strategic recommendations (e.g., consider the status of features outside of the MR&T during system operation) establish how the system may be enhanced beyond existing capabilities and authorities and will be advanced by senior leaders and decision makers.

A. EMERGENCY OPERATIONS PLANS

The following recommendations were developed based on lessons learned during the implementation of Emergency Operation Plans (EOP) by each District during the 2011 Flood. The highest priority EOP recommendations are listed first. The remaining recommendations are considered to be a lower priority because they are either a lower level of impact or they can be implemented without significant effort or coordination. These recommendations are categorized as operational. They were developed with input from all USACE Districts with MR&T components and may, at times, apply to some, but not all Districts.

1. Highest Priority Emergency Operations Plan Recommendations

- **Revisit the Chain of Command structure for Emergency Operation activities to ensure that decision makers have access to the most knowledgeable staff.** Emergency Managers in some Districts felt that they could have helped address and minimize some of the more controversial issues if they were in the field directly supporting the District Engineers during the decision making processes. Support offered by these staff would include providing and verifying information used by senior leaders to make critical decisions.

- **Assign MVD Representatives to Districts early on for regional flood events to assist with coordination**. The assignment of MVD Representatives to work directly with the Districts was a significant benefit to the District Emergency Operations activities. This should be considered as a standard practice for all regional flood events.

- **Take full advantage of Smartphone, FREEBOARD, & MICA Capabilities.** The tools were a significant benefit during the event and the expanding set of applications that are available should be continually exploited. ACE-IT does not currently allow Smartphones and steps should be taken to address this issue to improve the availability, distribution, and support of these devices. An organized and on-going effort to develop and apply these applications should be considered.

    - **Identify areas with limited cell phone coverage and work with appropriate entities to increase cell phone coverage in these areas. Update plans and identify and obtain equipment needed to ensure effective communication until cell phone coverage is expanded in these areas.** With the expanded use and reliance on cell phones, updates to all field-related plans should seek to identify areas without adequate cell phone reception. Once identified, the plans should identify alternative methods of communication and a means to provide it if radios or other equipment is needed. Also, consider working with cell phone service providers to expand coverage area if possible.

    - **Update pre-flood plans to better address new technologies (social media, Smartphones, etc.)** Many of the tools used during the 2011 Flood had not been utilized as extensively prior to the event. Consequently, decisions about how and when to use them were rushed, training was required, and some mistakes were made. To take complete advantage of these tools, pre-flood plans should thoughtfully incorporate them prior to the next event.

    - **Maintain sufficient supply of Smartphones for regional emergency use during a large event.** There was a shortage of Smartphones available at the beginning of the event. Additionally, there were process requirements that prevented efficient acquisition of more in a timely manner. An effort to maintain a sufficient supply of these valuable tools should be considered.

2. Additional Emergency Operations Plan Recommendations

- **Staff-up EOC and train early.** There was a shortage of trained staff to respond to the 2011 Flood. Districts should consider using the staff requirements needed to respond to the 2011 Flood as a basis for determining additional staffing and funding needs for future events and develop trained personnel accordingly.

- **Include public affairs section in EOC standard operation and EOP.** External Communications through coordination with the PAO was not consistently and effectively addressed in pre-flood plans. This adversely impacted some communications efforts. An effort to address that issue in future plan updates should be considered.

- **Coordinate early with non-Federal sponsors/stakeholders**. Some stakeholders expressed that early coordination would have alleviated many of their concerns and the lack of information presented problems for them. Districts should consider performing early coordination with key stakeholders and project sponsors to help initiate information sharing.

B. RESERVOIRS AND FORECASTING

The following recommendations were developed based on forecasting experience and the performance of Mississippi River Basin reservoirs during the 2011 Flood. The recommendations are considered primarily operational in their development and implementation. They are also considered strategic based on how they relate to operation of the Mississippi River Basin reservoirs as a system. A general strategic recommendation "Improve the overall operations of the Greater Mississippi River Basin reservoirs as a system" was developed based on operation of both MR&T and non-MR&T reservoirs during the 2011 Flood. A better understanding of operational impacts to the system, existing authorities, and the need to develop standard processes for operation and potential deviation directives would improve the operation of the greater Mississippi River Basin reservoirs as a system.

1. Reservoir and Forecasting Recommendations in Order of Priority

Priority 1. Improve NWS Forecasts and Communication Between the NWS and USACE Districts to Clarify Operational Requirements for MR&T Floodways. Steps should be taken to improve NWS forecasts and communication between the USACE Districts and NWS regarding MR&T floodway operation. Water control plans for the two floodways within MVN should incorporate the results of this effort and clearly lay out operational requirements based on NWS coordination and information. MVD Water Control offices should fully implement the Corps Water Management System.

Priority 2. Take Additional Steps To Improve the Accuracy of Forecasts. In spite of recent improvements in forecasting, several forecasting-related issues were highlighted and the public has expressed the need for additional improvement. To further improve the quality of river forecasting at all forecast offices within the Greater Mississippi River Basin, continue to implement the following initiatives/measures underway:

- Develop a HEC-RAS community model for the Mississippi River
- Continue tri-agency meetings to enhance collaboration
- Continue river forecaster's workshops to increase collaboration
- Utilize the Fusion Team as the primary coordinator of Tri-agency improvements in river forecasting

Priority 3. Develop a Standardized Deviation Directive Process. During the 2011 Flood, a Deviation Directive was given to several non-MR&T reservoirs. Reservoir Water Control Plans currently do not have a clear process for this nor were there standard processes in place to analyze conditions and communicate with upstream, downstream, environmental and local interests. If Deviation Directives continue to be an operational option, a process should be defined and incorporated into the Water Control Plans. Much of the uncertainty revolving around the use of these Directives involved the lack of an approved process. The process should be consistent with QMS and mirror the requirements for a major deviation that is presently defined. If applicable, as individual Water Control Manuals are updated, this process for Directives should be incorporated into the section of the manual that defines deviation processes. Furthermore, a process for deviation directives use/approval should be developed, reviewed, and codified in the appropriate ER and EM by the USACE water management community.

Priority 4. Incorporate Travel Time from Reservoirs and Document Associated Risk Considerations. When reservoirs were operated during the 2011 Flood, complete information related to travel times of flows/releases from the reservoirs was not readily available. This information should be developed and documented in advance so travel times from reservoirs can be used to make decisions and communicate impacts to stakeholders. Additionally, risk-based decisions should be documented and ensure that risk reduction at one location does not result in a net increase of risk within the river basin.

C. LEVEES AND FLOODWALLS SYSTEMS

The following recommendations were developed based on the performance of the MR&T System and the damages it sustained during the 2011 Flood. The levee and floodwall system recommendations are considered operational. Recommendation 1c is also considered technical in that analysis and redesign will need to be done to increase system resiliency and also strategic in implementation of its overarching goal.

1. Levee and Floodwall Recommendations in Order of Priority

Priority 1. All systems should be brought up to the minimally acceptable classification as quickly as funding allows.

- All FRAGO Classification 1 items are repaired or are in the process of being repaired.
- All FRAGO Classification 2 and 3 items will be repaired as quickly as funding allows.
- Some segments of the levee/floodwall systems were not tested in the 2011 event, but are believed to be deficient and should be further studied, and upgraded if required.
- Nearly 20 percent of the levee systems were rendered unacceptable by the 2011 Flood. This number is reasonable considering the magnitude and duration of the 2011 Flood. A level of damage is expected to occur due to significant flood events; as a goal the acceptable number of systems rendered unacceptable, should not exceed 20 percent to 30 percent. Increasing the resiliency of these systems will serve the dual purpose of minimizing the time and cost required to restore the systems following future events and will minimize the risk associated with subsequent events occurring before restoration efforts are complete.

Priority 2. The current Flood Fight Manual is from the early 1980s and should be updated to make the information more user friendly. The new manual, its use, and contents, should be communicated to all stakeholders through an organized outreach program, emphasizing problems and solutions identified in the past. Problems with sand boils are a major concern. The fine points of ringing sand boils should be included in revised drawings showing the proper ringing technique and should be stressed in a revised manual.

Priority 3. Apply the recommendations in the Armoring Manual for the HSDRRS. Significant effort went into developing an Armoring Manual for HSDRRS (dated Nov. 2011). Much was learned in the aftermath of Katrina and subsequent testing of armoring materials, geometry, and techniques. Application of the recommendations contained therein should minimize future tie-in/erosion issues. An effort should be made to ensure this information is appropriately transmitted to the other Districts via an appropriate technology transfer program.

Priority 4. Develop and Implement a formalized information transfer program to assist the Districts in better managing and operating the MR&T. The revised Flood Fight Manual, Armoring Manual, and discussion of acceptable damage and risk (resiliency) will be important topics for this program. The program would promote communication and understanding of design techniques and assess problems and opportunities associated with each District's flood fighting methods. This in turn will allow Districts to more effectively support each other.

D. FLOODWAYS

1. Highest Priority Floodway Recommendations. Four high priority recommendations were developed based on the performance of MR&T floodway components during the 2011 Flood. They include:

- **BPNM. Evaluate possible alternative methods of placing the BPNM floodway into operation.** The Memphis District is proceeding with a study to examine this issue and will present the results to the Mississippi River Commission for consideration.

- **Morganza. Scour protection, additional height, or both may be needed at the south guide levee and curtain wall if future operations are expected to continue to occur at progressively higher river stages.** The ultimate cause of these issues is the apparent change in stage-discharge relationship along this reach of the Mississippi River, whereby equal discharges appear to be occurring at higher stages with each passing flood. A detailed technical review of the present flowline should be performed to assess these changes, determine whether a revised flowline is warranted, quantify the risk reduction the MR&T system can truly provide, and inform changes to operation of the Morganza Floodway and/or remedial actions such as river dredging to increase channel capacity, if needed.

- **ORCC. A comprehensive sediment management program for the ORCC should be implemented, including maintenance dredging of the channels as needed.**

- **Bonnet Carré. Deficient levee sections downstream of the Bonnet Carré Spillway should be brought up to design grade.** The Bonnet Carré Spillway performed as needed during the Flood of 2011, diverting more flow than its design discharge under Project Design Flood conditions in order to protect deficient levee sections on the Mississippi River. downstream. These levee sections should be brought up to design grade so that during future floods the Spillway will not have to divert as much water.

The recommendations are considered primarily operational in nature. There are also some technical recommendations related to the need for modeling and analysis. Significant changes to the operation of floodways may also rise to the level of strategic recommendations due to required changes to current authorities to allow them happen. Additional details on the floodways and suggested enhancements to the system are as follows:

2. Additional Detail on Highest Priority Floodway Recommendations

- **BPNM Floodway.** The Flood of 2011 necessitated the first operation of the BPNM Floodway in 74 years, and the first under present operational procedures. This operation was not only a success, but it also provided the opportunity to capture lessons learned about how best to perform this operation in the future. The floodway crevasses are now being repaired to bring the floodway back to its pre-flood condition, so the system can function as it did before the operation. Under present policy, future operations of this floodway will be performed through artificial crevassing of the fuse plug levee sections, as was done in 2011. However, the MVM is moving forward with a study to evaluate possible alternative methods of placing the floodway into operation, to present to the MRC for consideration.

  In addition to this study, relatively minor operational changes are needed to improve the efficiency of the existing floodway activation procedure. These include adjustments to the loading and travel timeline of transporting the explosive agent to the site, closer coordination with the Coast Guard, better weather protection for the explosive agents, and better strategies for quick procurement of critical materials. Twenty-nine of these recommendations have been captured in the MVM and ERDC AARs, which are included in Appendix E, *Communications/ Collaboration*, so they are not duplicated here.

- **Morganza Floodway.** The 2011 Flood required the operation of the Morganza Floodway for the first time since 1973. This operation was not only a success, but it also provided the opportunity to capture lessons learned about how best to perform this operation in the future. Among the most important lessons learned was the importance of a framework of operational criteria that is both specific enough to minimize problems resulting from the inevitable unfamiliarity of performing an operation that occurs about once per professional career, and flexible enough to stay useful as conditions change. During the Flood, river stages were so much higher than during previous floods that the top of the Morganza Structure was taken into account during the decision making process to operate the structure, as the river threatened to overtop the structure before the threshold flow of 1,500,000 cfs (which the Floodway is intended to prevent) was reached.

  The damage at the Morganza Control Structure should be repaired and priorities should be established to identify the incremental steps required to effectively operate the structure within current capabilities to safely and effectively pass the project flood. Further, the challenges associated with the specified operational trigger, threat of structure overtopping at that trigger, potential for recurring stilling basin damage upon opening and potential threat to safe operations as scour occurs should be addressed.

  The 2011 operation was within the guidelines of the water control manual, but a study should be conducted to assess whether the manual should be revised to add an explicit trigger for operation based on maintaining freeboard at the Morganza Structure as well as the levees downstream. This operational criterion could remain effective regardless of changes in Mississippi River channel capacity. Assessment of other potential changes to the Morganza Water Control Manual is also needed, including changing the gate opening sequence to reduce scouring in the tailbay, adding more data to the pertinent data section, and revising and adding to the tables and charts to make them more useful.

The tailbay of the Morganza structure may require stronger scour protection and greater energy dissipation to prevent scour from approaching the structure, especially if it will continue to be opened at river stages higher than were anticipated when it was designed. Investigations into the best method(s) of providing this scour protection are ongoing. Scour protection, additional height, or both may also be needed at the south guide levee and curtain wall if future operations are expected to continue to occur at high river stages.

Assess the potential benefit of modifying the water control manual to contain plans to conduct surveys during a flood to determine and control scour progression during an operation. Additionally, a plan should be developed to study future system operational requirements. Analysis of the Morganza Structure, including the forebay, tailbay, and adjacent sections of the Mississippi River are needed to determine the performance of the structure for other extreme events. Models of the Morganza Floodway and Atchafalaya Basin should be developed to help inform Floodway operations and emergency preparedness.

- **ORCC.** The ORCC operation influences and is influenced by operation of the Morganza Floodway, and it shares some objectives with the Morganza Floodway and Bonnet Carré Spillway, so recommendations for this complex area follows:
    - The operational criteria at the Old River Overbank Structure should be re-evaluated. A fully functional Overbank Structure would permit closing portions of one of the other structures in the complex to conduct assessments, detect critical issues that could be rectified to prevent a failure. Additionally, gate hindrance or errant vessel impedance of flow could severely impact operations with little recourse without capability to redirect a portion of flow to the Overbank.
    - An engineering assessment followed by implementation of risk reduction measures with the goal of a fully functional overbank structure should be conducted. Potential actions include alterations to the gabion weir and stone blanket at the confluence of the Overbank and Low Sill outflow channels to eliminate the flow restriction and hydraulic jump concerns, providing needed flexibility for more severe or longer duration floods, and to provide flexibility to shift flows in response to unforeseen emergency situations.
    - The discharge computation procedures for the Mississippi River at Tarbert Landing, upon which the regulation of the ORCC is based, should be revisited to attempt to increase the accuracy degree of confidence of the results. Even under favorable conditions, discharge measurement in a large river may only be accurate to within 5 percent, so that a measurement of 1,500,000 cfs could be in error by 75,000 cfs or more. This is compounded by the apparent pulsing of flow that was observed in 2011, when multiple boats with high frequency acoustic instruments performed simultaneous discharge measurements, whereby flow increased and decreased sinusoidally by 300,000 cfs or more over the span of a few hours. The causes of this pulsing are now under study, but whatever the cause, it clearly increases uncertainty. These discharge measurements are used to create and adjust a stage-discharge rating curve at Red River Landing, which is then used to compute daily discharge and distribution of flow.

- A permanent discharge gage, with side-looking acoustic Doppler current profiler, data collection platform, and satellite antenna should be installed at the Tarbert Landing discharge range or suitable location nearby. This gage will provide near real-time discharge measurements to clarify operational decisions that are made on a daily basis at the ORCC. In addition it would provide information for risk-based decisions during future flood events, while also providing a wealth of data for examining the pulsing flow phenomenon.
- A comprehensive sediment management program for the ORCC should be implemented, including maintenance dredging of the channels as needed. The program should address excessive sediment that redirects flow, damages the channel banks, and causes overbank flow to occur at lower discharges, reducing access and visibility.

- **Bonnet Carré Spillway.** The Bonnet Carré Spillway performed as needed during the Flood of 2011, diverting more flow than its design discharge under PDF conditions in order to protect deficient levee sections on the Mississippi River downstream of the structure. These levee sections should be brought up to design grade so that during future floods the Spillway will not need to divert as much water. Additionally, Better computer models of the Spillway should be developed to help determine the maximum flow that can be diverted, without overtopping guide levees or creating dangerous scour. If linked to larger models of Lake Pontchartrain, these could also help address environmental concerns related to Spillway operation.

  US Highway 61 (Airline Highway) and most of the railway crossings at the Spillway guide levees are constructed below the height of the guide levees. This causes seepage through the railway ballast under the railroad tracks and can allow water to spill onto the highway. As a result, Spillway staff must build and maintain temporary embankments on the highway right-of-way to prevent water from flowing onto the road. Solutions such as raising the roadway, replacing the railway ballast, or a permanent barrier should be investigated.

- **West Atchafalaya Floodway. Public outreach on the possibility of operating the West Atchafalaya Floodway should be continued.** Because it was not operated in 2011, no new lessons learned regarding the West Atchafalaya Floodway were captured or used to form recommendations. However, the experiences of operating BPNM Floodway and the Morganza Floodway, both of which are less densely developed than the West Atchafalaya Floodway, provide important lessons learned on the potential risks for future development in this area. Public outreach on the possibility of operating the West Atchafalaya Floodway should be continued given the relatively large population living within it**.**

E. BACKWATERS

The following recommendations were developed based on the performance of MR&T backwater components during the 2011 Flood. Although backwater levees were not operated during the Flood, lessons learned and recommendations were still developed based on observations in these areas. Recommendations developed for the Yazoo River and Red River Backwater are considered the highest priority at this time. The recommendations are considered a combination of both operational (e.g., installation of new river gages) and technical (e.g., development of new hydraulic models).

1. Highest Priority Backwater Recommendations

- **Yazoo River Backwater Area. Additional river gages should be installed to aid in operation of the Yazoo Backwater Levee. Also create a hydraulic model to help inform future operation of the Yazoo Backwater Levee.** Although it was not operated during the Flood of 2011, river levels came within inches of putting the Yazoo River Backwater Area into operation, and flood fight operations were undertaken to minimize damage in the event of operation. Two major recommendations emerged from this experience.
    - To increase understanding of hydrodynamics in the vicinity of the Yazoo River Backwater Area and assist with future flood fight operations, two satellite-enabled gages should be installed near the intersection of the Mississippi River main line levee and the Yazoo Backwater Levee. One gage should be located upstream of the intersection along the mainline Mississippi River while the other should be located downstream of the intersection on the Yazoo Backwater Levee. These gages will be used to monitor the difference in water surface elevation as water flows over the spur dike at the intersection of the two levees. Knowledge of the complex water surface and how it changes at this location is integral to operation of the Yazoo Backwater area.
    - Additionally, a numerical hydraulic model should be created to help investigate the impacts to the Yazoo Backwater levee of a simultaneous Yazoo River headwater flood and a Mississippi River backwater flood. This model will be extremely helpful when preparing for future operation of the Yazoo Backwater Area.

- **Red River Backwater Area. Create a hydraulic model to help inform future operation of the Red River Backwater.** Although its fuse plug levee was not overtopped in 2011, significant backwater storage did occur in the overbank areas of the Red River, with both the Red and Black rivers flowing backward (northward) at times during the flood. This backwater effect creates uncertainty for flow computation, complicates operations at the ORCC, and prolongs the duration of flood conditions. To better understand this effect, a numerical hydraulic model of the lower Red River should be created to evaluate the effects of backwater from operation of the ORCC (and, potentially, the Morganza Floodway) on the Red River area. This model, if coupled to a model of the Mississippi River already under development, will aid in quantifying the effect of operation of the Morganza Floodway on stages in the Mississippi River as far upstream as Natchez and Vicksburg.

  During the flood, the NWS issued forecasts both with and without operation of the Morganza Floodway, with surprisingly large differences shown between the two on the gages at Vicksburg and Natchez. Numerically modeling this area with a calibrated hydraulic model will improve the accuracy of inundation mapping, improve forecasting accuracy, and help quantify the overall risk reduction provided by the Morganza Floodway, ORCC, and Red River Backwater Area.

F. INTERIOR DRAINAGE

The following recommendations were developed based on the performance of MR&T interior drainage components during the 2011 Flood. The following recommendations below are considered primarily operational in nature.

1. Highest Priority Interior Drainage Recommendations

- **St. Francis River Basin. Proceed with approved courses of action to repair the identified damages as provided by the 2012 Disaster Relief Act. Damages should be repaired during a time less likely to require pumping operations in order to minimize risk to protected areas.**

- **Bayou Chene. Perform a study to assess if on site pumping capability should be considered as part of emergency measure placed at this location during future events. A permanent structure has been proposed by the local sponsor near the location of the emergency measure and this should also be assessed to determine if it enhances flood risk management in this area.** Assessment of the structure should include allowing closure of the bayou for protection against flooding from the Atchafalaya floodway and storm surge. The addition of a pumping facility should also be assessed to allow for the drainage within the bayou when the proposed permanent structure is closed.

2. Additional Interior Drainage Recommendations

- **St. John's Bayou – New Madrid Floodway. Proceed with approved courses of action for the St. John's Bayou New Madrid Floodway Project with all critical repairs completed by the 2013 flood season.** Continue to use the St. John's Bayou Gravity Structure and the BPNM Floodway in accordance with existing project authorizations.

- **Yazoo River Area. Successful operation in 2011 showed that structures should continue to be operated as designed.**

- **Lake Chicot Pumping Plant. Successful operation in 2011 showed that structure should continue to be operated as designed.**

- **Upper Point Coupee Parish Loop. The gate seals on the Point Coupee Drainage Structure should be repaired to prevent leakage during events and further damage to the structure.** If a rain event occurs during a high river event, the Point Coupee Pumping Station should be operated in conjunction with the Point Coupee Drainage Structure. Local partners and landowners should maintain Johnson Bayou clear prior to high river season. Unrestricted use of the bayou for internal drainage will reduce the need to operate the pump station.

- **Bayou Courtableu Drainage Structure and Bayou Darbonne Drainage Structure. Plan should be developed to specifically address interior drainage when the Morganza Control Structure is operated.**

- **Hanson Canal, Franklin Canal, and Yellow Bayou. Additional drainage structure(s) should be installed as considered in the Atchafalaya project plan.**

G. CHANNEL IMPROVEMENTS

The utilization of the features of the Channel Improvement Project has been successful in resisting the erosive forces of the river in the vast majority of cases. Consequently, the design criteria by which the features are designed and constructed is proven. However, the 2011 Flood demonstrated that there are some inadequacies. Subject to economic considerations, the following recommendations should be considered.

The following channel improvement recommendations are listed in order of priority and are primarily considered operational.

1. Channel Improvement Recommendations in Order of Priority

Priority 1. Provide additional channel improvement measures in critical areas. In critical areas, such as in the immediate vicinity of a mainline levee, consideration should be given to providing additional channel improvement measures. These additional measures include dikes with flatter slopes, more scour protection where a dike intersects the bank, dragging the revetment higher up on the bank, providing toe protection for the levee, armoring the levee slope, planting tree screens, etc. The 2011 Flood pointed out that even though the Channel Improvement project was incredibly successful, there are still weaknesses with some Channel Improvement measures in various areas. For economic reasons, there will always be weaknesses that will require repair after major flood events, but we should make every effort to avoid having weaknesses that could result in a mainline levee being compromised.

Priority 2. The ACM sinking and grading units should receive major rehabilitation or be replaced. The Sinking Unit has been in use for several decades and has been repaired, modified, and upgraded on numerous occasions. Although the ACM has been very successful at maintaining the river bank alignment and configuration for flood risk management, navigation and environmental purposes for several decades, the 2011 Flood event demonstrated that major flood events will damage revetments. If left unrepaired, some damages would allow the river to change course. It is crucial to the Nation's economy that the river channel be maintained in its current location and alignment. To ensure that the Corps maintains the capability to construct new revetments and repair existing revetments after floods, the Sinking Unit must be maintained. Considering the age of the Sinking Unit and the importance of the river channel, it is recommended that the Sinking Unit be evaluated to determine its capability to perform the intended function in the future. Consideration should be given for major rehabilitation or replacement of the Sinking Unit to reduce the risk of a major malfunction which could adversely affect the Corps' ability to maintain the channel. For the Sinking Unit to perform its function properly, the river bank must be properly prepared to accept the ACM. This bank preparation is performed using the Grading Unit. Some of the equipment used by the Grading Unit has also been in operation for decades. Therefore, consideration should also be given for major rehabilitation or replacement of the equipment used by the Grading Unit.

Priority 3. Increase pace of implementation of channel improvement project features. The 2011 Flood demonstrated that major flood events will damage the channel and previously constructed channel improvement features. If the channel is exposed and damages left unrepaired, the river could change course and levees could be threatened. It is crucial to the Nation's economy that the river channel be maintained in its current location and alignment.

Priority 4. Incorporate tree screens at vulnerable top bank/overbank locations. Overbank flows generated a significantly greater amount of scour and damage where trees were sparse or not present. Consideration should be given to incorporating tree screens behind top bank at vulnerable locations. Developing design criteria to incorporate tree screens into the Channel Improvement Project is recommended.

Priority 5. Extend Articulated Concrete Mattress (ACM) revetment farther into the channel and higher up on the riverbank. Extending the revetment farther into the channel and higher up on the bank would likely have reduced the scour that occurred at the toe and the upper bank.

Another consideration for reducing the potential for upper bank erosion would be to increase the size and/or thickness of the stone currently being used.

Priority 6. Modify dikes to reduce damages caused by large flood events. Considering that some dikes sustained scour damage where the dike joins the bank, providing increased erosion protection on the downstream side of the dike could prevent some of that type of damage. In addition, increasing the dimensions of the root dike and key trench and/or extending the bankhead paving should be considered to provide a greater level of protection from flanking of the structure.

H. CHANNEL CAPACITY

The following recommendations were developed based on the operation and performance of the MR&T System during the 2011 Flood. All of the following channel capacity recommendations are considered primarily technical in nature.

1. Highest Priority Channel Capacity Recommendations

- **Assess effect of floodway operation, bedform changes, and secondary flow on overall flow**
- **Analyze the MR&T to identify areas within the system that may not be providing the authorized level of protection**
- **Analyze complex flow patterns at Morganza, Bonnet Carré, and ORCC**

2. Additional Channel Capacity Recommendations and Supporting Information. It is important to understand why, for higher flows on the Mississippi River in the MVN, ADCP measurements yield flows that are consistently lower than flows determined using conventional measurements. A change in measurement technique to ADCP methodology results in a higher stage for the same flow.

The quality control review of the ADCP measurements has resulted in the following recommendations.

- **Upgrade ADCP firmware used for overbank flow measurements**
- **Improve documentation of ADCP self tests and moving bed tests**
- **Upgrade GPS receivers used with ADCPs to have at least 2 decimal minute accuracy on position and velocity and provide data output at 2 Hz or faster.** Further conclusions and ADCP recommendations will be determined as the quality control review and assessment continue.
- **The effect of operation of the ORCC and Morganza Floodway, bedform changes, and secondary flow structure transitions on flow measurements should be assessed.** The analysis of discharge measurements should expand to other measurement sites within MVD. The MVN is pursuing funding to upgrade the Red River Landing gage with instruments to continually measure velocity; MVN should take additional measurements during future flood events to better define the pulsing phenomenon.
- **Analyze the ORCC and other areas of the MR&T System as recommended by the Committee on Channel Stabilization.** Channel capacity changes have been seen within the MVN; the extent of the changes outside the vicinity of the ORCC has yet to be determined. The Committee on Channel Stabilization reviewed the preliminary results of the ERDC study and concluded that operation of the ORCC has changed the base conditions and is in all likelihood contributing to geomorphic changes on the Red, Atchafalaya, and Mississippi

Rivers. The Committee recommended continued analysis of the system, including a determination if the levee system is providing the authorized level of protection.

- **Conduct further flow analyses.** The Districts within MVD have identified specific post flood study needs that include analysis of complex flow patterns at Morganza, Bonnet Carré, and ORCC; the effect of channel changes and future sedimentation trends on water surface profiles; analysis of the ORCC as recommended by the Committee on Channel Stabilization; and evaluation of operational procedures at Morganza, Bonnet Carré and ORCC. These studies will support the review to determine if a new flowline will be needed and provide information to update water control documents.

I. ENVIRONMENTAL AND CULTURAL RESOURCES

The environmental and cultural resources recommendations are largely centered on suggestions to standardize intra- and interagency coordination, study possible adjustments to the operation of the flood control system to enhance environmental and cultural resource protection, develop mechanisms to facilitate sampling and monitoring, and develop programs to enhance channel stability and riparian and aquatic habitat. Overall, the environmental and cultural resources recommendations are considered operational. There are also some technical aspects of these recommendations related to developing regional tools and processes (e.g., web-based database development). The need to incorporate more official environmental and cultural resource considerations in FRM may also be considered a strategic recommendation.

1. Highest Priority Environmental and Cultural Resource Recommendations in Order of Priority

Priority 1. Institutionalize both internal and external environmental and cultural resources regional response teams. Internal teams will include representatives from all of the affected Districts. External teams will include interested agencies and tribes. Define criteria for activating the teams and lay out plans for internal and external coordination of teams. Include these plans in emergency response plans or other documents for future utilization.

Priority 2. Investigate methods for slowly flooding floodways to allow for wildlife escape and to prevent scouring and erosion of cultural resource sites, as well as slowly closing floodways to facilitate rescue of fish species.

Priority 3. Investigate the feasibility of establishing a program to plant and rehabilitate tree screens along the river to stabilize banks and decrease scouring while also providing habitat and potentially shading a portion of the streamside.

Priority 4. Investigate the possibility of setting aside contingency emergency funding for environmental work and establishing advanced MOAs for monitoring, for example, with the USGS for water quality monitoring. Establish system-wide water quality monitoring protocols under these agreements.

Priority 5. Explore the advanced development of programmatic agreements such as Section 7 Consultation for T&E species with US F&W Service and pursue cultural resources programmatic agreements (36 CFR 800.14) and regional programmatic agreements for emergency Section 106 consultation.

2. Additional Pre-Flood Environmental and Cultural Resource Recommendations

- **Environmental.** The 2011 flood occurred just 3 years after the previous opening of the Bonnet Carré Spillway in 2008. Because of this, many agency personnel were able to leverage their experience managing the impacts of the 2008 flood to improve their flood management methods in 2011, which increased the efficiency and benefit of their actions. Accordingly, many recommendations focus on the need to codify the most successful activities that took place in the days leading up to and during the flood. These activities included:
    - **Establishing and publishing procedures for activating an internal, intra-divisional environmental team and instituting a meeting protocol for the team (Appendix F, Section I.)**
    - **Establishing and publishing procedures for activating an external, interagency environmental team and instituting meeting protocol (Appendix F, Section I.)**
    - **Developing consistent water-quality monitoring procedures and identifying rapid contracting mechanisms**
    - **Initiating emergency threatened and endangered species (T&E) consultation**
    - **Creating a web-based database or portal for standardized access to environmental data (e.g., water quality, fisheries, sediment, discharge, etc.)**
    - **Describing and cataloging invasive and nuisance species that may spread or otherwise be affected by flood conditions. Determine if any measures can be taken for managing invasive and native nuisance species during flood events.**

- **Cultural Resources.** Similarly, the observed need to utilize Corps and interagency communication channels during the early stages of a flooding event led to the following recommendations:
    - **Establish and publish procedures for activating an internal, intra-divisional environmental team and instituting a meeting protocol for the team** (Appendix F, *Environmental and Cultural Resources*)
    - **Establish and publish procedures for activating an external, interagency environmental team and instituting meeting protocol** (Appendix F)
    - **Notify culturally-affiliated tribes regarding possible floodway operations; mail draft protocols for the recovery and final dispositions of human remains should any be uncovered by soil erosion and scour**

3. Additional "During the Flood" Environmental and Cultural Resource Recommendations

- **Environmental.** Environmental data relating to spillway operation during floods is relatively time sensitive and must be collected immediately before the spillway activation and during its operation. To expedite response times and enhance readiness regarding environmental, the following tasks are recommended:
    - **Foster partnerships with others to quantify effects to oysters and other estuarine resources**
    - **Establish protocols and assign teams for the rescue of T&E species**

- **Maintain regular (weekly or more/less often depending on level of risk) communication with others, including Federal, state, local agencies, non-governmental organizations, and academics**
- **Coordinate with individuals and organizations collecting field data**
- **Develop a public communication plan on the status of Lake Pontchartrain and other waterbodies with high recreational use**
- **Consider gradual closure of Bonnet Carre Spillway, as was done in 2008 compared to the rapid closure in 2011, to prolong attraction flows for entrained pallid sturgeon to move upstream where they are more readily captured and rescued**

- **Cultural Resources.** During future floods, it is recommended that cultural resource specialists codify processes to:
  - **Update consulting and culturally-affiliated tribes using teleconferences and emails on a weekly basis**
  - **Based on tribal input, develop plans to revise protocols for the treatment and disposition of human remains uncovered by scouring.**

4. Additional Post-Flood Environmental and Cultural Resource Recommendations. Experience from the 2011 flood has shown that, as the floodwaters recede, 1) species which were trapped may require assistance; 2) aquatic areas flooded with nutrient-rich river waters may develop algal blooms; and 3) assessment of cultural resources damages must be initiated. These problems will likely occur during future floods and will need to be addressed.

- **Environmental.** The number of T&E species is likely to increase in the future due to new stresses initiated by anthropogenic development and climate change, enhancing the need to develop comprehensive yet easy-to-operate action plans. To quickly and more efficiently address these two problems, the following tasks are recommended:
  - **Establish the process for conducting T&E species rescue operations, funding mechanisms, and coordinating processes**
  - **Establish mechanisms to continue to identify, capture, and archive environmental data collected before, during, and after the flood**
  - **Continue interagency meetings/conference calls to summarize and share data**

- **Cultural Resources**. To increase the efficiency of our post-flood response in regards to cultural resource preservation, the following tasks are recommended:
  - **Conduct a LIDAR imagery evaluation in a GIS context as soon as flood waters recede to determine impacts to recorded cultural resources sites from scour**
  - **Consult with SHPO and affiliated tribes as required in programmatic agreement to mitigate adverse effects of floodway activation through site restoration or data recovery**

5. Additional Environmental and Cultural Resource Recommendations Related to Proactive Planning for Future Events. Previous flood reports paid little attention to management issues relating to environmental and cultural resources. However, because of increased public awareness and new legislation, these issues play an increasingly important role in the Corps' flood fighting and management mission. This trend is expected to continue in the future. There are several recommendations that the Environmental and Cultural Resource teams developed which should be considered during non-flood years in preparation for the next significant food event:

- **Environmental**
  - **Re-evaluate the operations of floodways as a system and undertake the evaluation of the current operation plans**
  - **Evaluate options for changing the speed of both opening and closing the structures**
  - **Evaluate the order of operating the structures**
  - **Generate Environmental/Cultural Resource Operating Plans, similar to the Water Control Plans, which are linked to table top exercises, and undergo periodic reviews and updates**
  - **Investigate the possibility of setting aside contingency emergency funding for environmental work, perhaps within the EOC framework**
  - **Develop programmatic Section 7 Consultation for T&E species with the USFWS and establish mechanisms for periodic updates**
  - **In collaboration with channel improvement and bank stabilization efforts, explore the possibility of developing a tree screen establishment program**
  - **Investigate establishing advanced MOAs with USGS for water quality monitoring and other agencies to have agreements in place prior to emergency operations**

- **Cultural Resources**
  - **Develop programmatic agreements (36 CFR 800.14)**
  - **Complete cultural resources surveys in floodways as required by PAs or SHPOs (when PA has not been developed)**
  - **Develop regional programmatic agreement for emergency Section 106 consultation (1 year minimum)**
  - **Follow protocols approved by SHPOs and tribes for the treatment and disposition of human remains uncovered by scouring**

J. DATA INVENTORY AND MANAGEMENT

The following recommendations pertain to the handling and long-term viability of post flood data and envelop data gathering, handling, and preservation. The recommendations are considered both technical in their development and operational in their implementation. More detailed discussion of each recommendation is presented in Appendix H, *Data Management*.

1. Data Inventory and Management Recommendations in Order of Priority

Priority 1. Document control must be an assigned, dedicated function for the MR&T Project. Currently, document management practices vary widely across the Division reducing efficiency and accuracy. For the Division to improve internal data handling practices, leadership must establish document management as a priority across the operational area of the MR&T system.

Priority 2. Create a Flood Data Center that compiles, preserves, and increases access, internally and with partners, for all regional Corps flood and post-flood information. The Center's scope would include historic and current flood information. The Center's mission would include capture and organization of historic data yet remain forward focused for new data sets using a combination of traditional archival techniques and state of the art data management and warehousing technologies.

Figure IX-1 outlines the basic structure of the Flood Data Center. The Center's objectives are to:

- complete comprehensive flood data sets for MVD and its partners;
- provide in-house reformatting of historic documents for better access;
- move to completely electronic circulation collection;
- preserve a safety copy of original documentation, maintaining original formats as required; and
- provide a single center to manage and serve all customer reference requests.

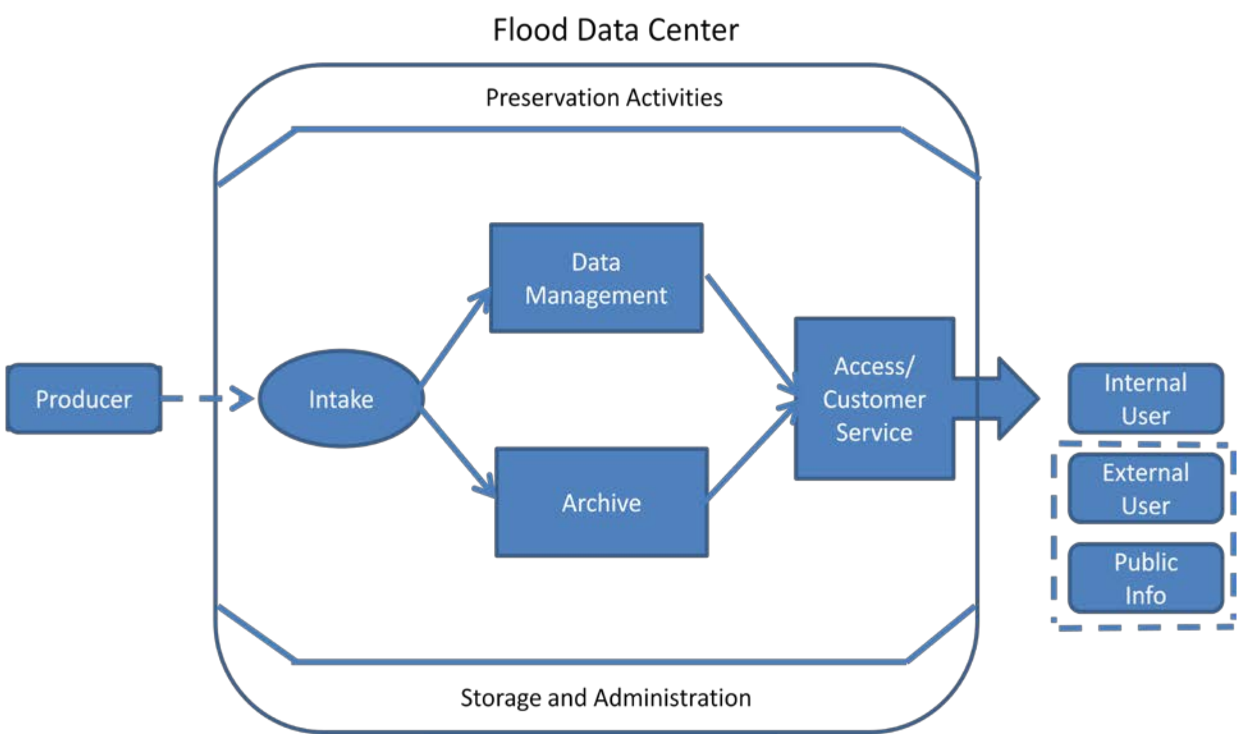


Figure IX-1. Flood Data Center Structure

Priority 3. Task archivists and records professionals to locate, inventory, and address MVD historic flood materials to have a complete spectrum of available flood related data. Use a simplified database with POC information for responsible entity for access.

Priority 4. Adopt a more centrally directed post-flood data capture and standardization process that stresses shared systems to mitigate the risk of potential loss of data and records due to current ad hoc local storage practices, usage, and differences in handling. The continuation of the current system threatens Corps data and ability to respond efficiently and intelligently.

Priority 5. After data gathering has concluded, direct handlers throughout MVD to follow preservation activities outlined in the guidebook (Appendix I, *Data Management*) and provide resources in the coming years to revisit and perform preservation needs assessment at a designated Flood Data Center or at the local user level.

K. COMMUNICATIONS AND COLLABORATION

1. Highest Priority Communication Recommendations in Order of Priority. The following recommendations were developed through a process of public and stakeholder meetings, interviews, and intra- and interagency evaluations. All the communication recommendations are considered to be primarily operational in nature.

Priority 1. Provide mapping consistency between Districts, coordinate mapping sooner, and coordinate mapping with other agencies; provide mapping in multiple formats and allow the public to easily identify where they are on a map (pdf, Google Earth, etc.).

Priority 2. Send important information to other agencies (levee boards, etc) before releasing to the public, but continue use of social media for general information (similar to a press release).

Priority 3. Continue daily conference calls during emergency operations, ensuring that all necessary agencies are included.

Priority 4. Establish relationships and direct lines of communication with river industry decision makers; keep up these relationships between floods.

Priority 5. Involve environmental NGOs in recovery efforts consistent with policy and authorities.

Priority 6. Communicate recovery efforts to MR&T System Stakeholders.

Priority 7. Publicize and share results of PFRs with partner agencies.

2. Additional Internal USACE Communication Recommendations

- **Ensure that personnel are sufficiently equipped in accordance with their role, all equipment is operable, and employees know how to use equipment.**
- **Establish consistency between districts and other agencies in regards to modeling, mapping, reporting, briefings, and forecasts.**
- **Provide additional Emergency Operations training between flood events to partner agencies and stakeholders.**
- **Continue use of android phones to send locations of sand boils, etc back to the office.**
- **Keep the organization charts up to date.**
- **Educate Corps employees and flood workers on public affairs and making statements on behalf of the Corps.**

- **Expand the pool of potential LNOs and train prior to next event; provide with District tools and ensure they are included in necessary briefings/updates to ensure they remain fully informed/SA.**
- **Implement ProjectWise as a repository for gage data and all pertinent flood fight information.**
- **Use the chain of command so employees do not take action on behalf of the District without approval and without the proper authority.**
- **EOC should ensure requests for IT support are forwarded to ACE-IT at the District.**
- **One District/Division should take the lead with each state to provide "One Door to the Corps" and provide consistency Input will be provided by all districts/divisions.**
- **Improve internal information sharing.**
- **Include public affairs section in the EOC SOP; one POC be identified to oversee all public meetings, and emergency personnel be educated on procedures regarding public meetings.**

3. Additional Partner Agency and Organization Communication Recommendations

- **Work with the NWS through the fusion team to explore the potential for official NWS forecast to be released by NWS earlier in the day.**
- **Work between floods to establish relationships with other governmental and non-governmental agencies (i.e., River Industry Decision Makers, Environmental NGOs, Levee Boards, etc.) to ease the exchange of information and increase communication before, during, and after flood events (i.e., preparedness, response and recovery).**
- **Supply EOCs with multi-agency personnel, resulting in a major communication improvement.**
- **Provide a Corps member to represent Corps issues within the USCG Command Center.**
- **Actively participate in the Joint Information Center (and other state equivalents) during flood events, and inform public affairs and emergency management personnel of its purpose and capabilities for inclusion in their planning.**
- **Continue daily conference calls during emergency operations, ensuring that all necessary agencies are included.**
- **Establish consistency between districts and other agencies in regards to modeling, mapping, reporting, briefings, and forecasts.**
- **Update existing distribution lists prior to next event.**
- **Publicize and share results of the PFRs with our partner agencies.**

4. Additional Public Communication Recommendations

- **Continue communication with public but increase efforts to publicize public meetings.**
- **Involve PAO and security in public meetings.**

- **Continue use of social media for general information to the public (similar to a press release), but send important information to other agencies (levee boards, etc) before releasing to the public; coordinate with PAO and EOC prior to event.**
- **Use the time between flood events to educate the public on the risks of living in a floodway or behind a levee and how to understand gage readings (gage vs elevation).**
- **Make Corps websites more visible.**

L. MR&T SYSTEM RECOMMENDATIONS SUMMARY

A systemic assessment of the MR&T System's operational and structural performance during the 2011 flood was conducted to identify opportunities to better restore, sustain, and improve the system. Table IX-1 displays a comprehensive and prioritized set of recommendations that should be considered in addressing the System's weaknesses and vulnerabilities. The recommendations also identify opportunities that should be further analyzed to improve current MR&T processes and components.

The recommendations are divided into three main categories (i.e., strategic, operational, and technical) to help establish the most appropriate approach to advancing them. Technical recommendations (e.g., modify the design of a levee) will be evaluated and moved forward primarily by engineers and MR&T component experts. Operational recommendations (e.g., change operating plan) will be examined and implemented by MR&T component experts, managers/operators, flood fighters, and decisions makers. Strategic recommendations (e.g., consider the status of features outside of the MR&T during system operation) establish how the system may be enhanced beyond existing capabilities and authorities and will be advanced by senior leaders and decision makers.

The recommendations in table IX-1 are also organized by major MR&T System component type and sorted by an initial priority. The initial priority was assigned by the PFR team to help identify the recommendations with the greatest potential to improve the performance of the MR&T System. Priorities were established within each component group and were identified in rank order (e.g. 1-5) or by having a number of component recommendations identified as high priority (e.g., several Floodways recommendations ranked as 1). Lower priority recommendations were not assigned a numerical rank at this time. These priorities will likely change as evaluations of the recommendations are advanced and additional information becomes available. The rankings will also change and be further refined as decision makers and senior leaders establish final priorities across all component categories.

The "Component" column in table IX-1 identifies the primary MR&T System component group that developed the recommendations. Further details on these recommendations and the information used in developing them can be found in the component sub-sections of this and other major sections of the PFR. The recommendations presented here are considered preliminary and have not yet been fully scoped or vetted. The next steps in their advancement will include further screening, regional prioritization, refinement, detailed scoping, and analysis. Some of the recommendations provided are already moving forward (e.g., BPNM operation assessment, examination of river flow changes, etc.) and will continue to be advanced. The process of implementing the PFR recommendations will result in improved performance of the MR&T System and further reduce flood risks within the LMRV.

The following table presents a categorized list of high priority overarching system recommendations and preliminary component team recommendations for improving performance of the MR&T. The bolded overarching system recommendations capture the main themes of the many detailed component team recommendations which would be nested within them. The recommendations have been grouped into three main categories (strategic, operational, and technical) to help establish the most appropriate approach to advancing them. They are also listed by component in an initial priority order established by the PFR component teams. This allows the reader to quickly locate additional information about the development of key recommendations in this and other component sections of the PFR. The next steps in advancing these preliminary recommendations will include further screening, combining, regional prioritization, refinement and detailed scoping for implementation by a regional multi-district and division team.

Table IX-1. MR&T System Recommendations

Strategic Recommendations		
Priority	**Recommendation**	**Component**
1	**Use information from the PFR effort to inform repair of the MR&T System**	**Overarching System**
1	**Use information from the PFR effort to inform completion of the MR&T System**	**Overarching System**
1	**Coordinate regional "triage" effort to prioritize, refine and implement PFR recommendations**	**Overarching System**
1	Improve the overall operations of the greater Mississippi River Basin reservoirs as a system	Reservoirs/Forecasting
1	Increase levee resiliency so fewer levee systems are made unacceptable by major floods	Levees
1	Examine and implement operational changes to MR&T floodways to improve performance	Floodways
1	Explore ways to include environmental and cultural resource considerations in flood risk management	Environmental/Cultural

Operational Recommendations		
Priority	**Recommendation**	**Component**
1	**Update Operation Manuals, Communications Plans, and SOPs using PFR information**	**Overarching System**
1	**Regionally standardize communication with MR&T stakeholders and landowners**	**Overarching System**
1	Revisit Chain of Command for Emergencies/Emergency Managers accompany DEs in field	Emergency Ops Plans
1	Assign MVD Representatives to Districts early for regional flood events	Emergency Ops Plans
1	Take full advantage of Smartphone, FREEBOARD, & MICA Capabilities	Emergency Ops Plans
2	Identify areas with limited cell phone coverage and work to expand coverage and prepare accordingly	Emergency Ops Plans
2	Update Pre-flood plans to better address new technologies (social media, Smartphones, etc.)	Emergency Ops Plans
2	Maintain sufficient supply of Smartphones for regional emergency use	Emergency Ops Plans
	Staff-up EOC and train early	Emergency Ops Plans
	Include public affairs section in EOC standard operation and EOP	Emergency Ops Plans
	Coordinate early with Non-Federal sponsors/stakeholders	Emergency Ops Plans
1	Improve NWS forecast communication between the NWS & districts to improve floodway operation	Reservoirs/Forecasting
1	MVD Water Control offices fully implement Corps Water Management System	Reservoirs/Forecasting
2	Take additional steps to improve the accuracy of forecasts [1]	Reservoirs/Forecasting

[1] Responsibility for implementation of this recommendation would lie with the Fusion Team

Operational Recommendations (cont.)		
Priority	**Recommendation**	**Component**
2	Continue Tri-agency meetings to enhance collaboration on forecasting	Reservoirs/Forecasting
2	Continue river forecaster's workshops to increase collaboration	Reservoirs/Forecasting
2	Utilize the Fusion Team as primary coordinator of improvements in river forecasting	Reservoirs/Forecasting
3	Develop a standardized deviation directive process for reservoir operation	Reservoirs/Forecasting
4	Incorporate travel time information from reservoirs and document associated risk considerations	Reservoirs/Forecasting
1	Bring all levee systems up to a minimally acceptable rating as quickly as funding allows	Levees
2	The Flood Fight Manual should be updated and communicated through an outreach program	Levees
3	Apply the recommendations in the Armoring Manual for HSDRRS (dated Nov. 2011)	Levees
4	Develop and implement a formalized information transfer program	Levees
1	Scour protection, additional height, or both may be needed at the Morganza south guide levee	Floodways
1	A comprehensive sediment management program for the ORCC should be implemented	Floodways
1	Deficient levee sections downstream of Bonnet Carré should be brought up to design grade	Floodways
	A discharge gage should be installed at the Tarbert Landing to clarify ORCC operation	Floodways
	Public outreach on the possibility of operating the West Atchafalaya Floodway should be continued	Floodways
1	Additional river gages should be installed to aid in operation of the Yazoo Backwater Levee	Backwater
1	Proceed with approved courses of action to repair St. Francis River Basin damages	Interior Drainage
1	St. Francis River Basin repairs should occur during times less likely to require pumping	Interior Drainage
	Proceed with approved courses of action to repair St. Johns Bayou New Madrid Floodway	Interior Drainage
	Continue to use St. Johns Bayou Gravity Structure in accordance with project authorization	Interior Drainage
	Yazoo River Area structures should be operated as designed	Interior Drainage
	Lake Chicot Pumping Plant structure should be operated as designed	Interior Drainage
	Gate seals on the Point Coupee Drainage Structure should be repaired	Interior Drainage
	Point Coupee pumping station and drainage structure should be operated in conjunction	Interior Drainage
	Local partners and landowners should maintain Johnson Bayou prior to high river season [1]	Interior Drainage
	Bayou Courtableu and Darbonne structures: develop operating plan for Morganza operation	Interior Drainage
	Install additional structures at Hanson/Franklin Canals & Yellow Bayou per the Atchafalaya plan	Interior Drainage
1	Provide additional channel improvement features in critical areas	Channel Improvement
2	The ACM sinking and grading units should receive major rehabilitation or be replaced	Channel Improvement
3	Increase pace of implementation of the channel improvement project features	Channel Improvement
4	Incorporate tree screens at vulnerable top bank/overbank locations	Channel Improvement
5	Extend ACM revetment farther into the channel and higher up on the bank	Channel Improvement
6	Modify dikes to reduce damages caused by large flood events	Channel Improvement

[1] Responsibility for implementation of this recommendation would lie outside the Corps

Operational Recommendations (cont.)		
Priority	**Recommendation**	**Component**
	Take additional measurements during future floods to better define the pulsing phenomenon	Channel Capacity
1	Institutionalize environmental and cultural resources regional response teams	Environmental/Cultural
3	Establish a program to plant and rehabilitate tree screens along the river to stabilize banks	Environmental/Cultural
4	Investigate possibility of setting aside contingency emergency funding for environmental work	Environmental/Cultural
5	Explore the development of programmatic agreements for emergency environmental work	Environmental/Cultural
	Develop consistent water-quality monitoring procedures and identify rapid contracting	Environmental/Cultural
	Initiate emergency threatened and endangered species (T&E) consultation	Environmental/Cultural
	Describe and catalog invasive and nuisance species that may spread during a flood	Environmental/Cultural
	Notify culturally-affiliated tribes regarding possible floodway operations	Environmental/Cultural
	Foster partnerships with others to quantify effects to oysters and other estuarine resources	Environmental/Cultural
	Establish protocols and assign teams for the rescue of T&E species	Environmental/Cultural
	Maintain regular communication with partners/stakeholders to enhance response/recovery	Environmental/Cultural
	Coordinate with individuals and organizations collecting field data	Environmental/Cultural
	Develop public communication plan on status of Lake Pontchartrain and other water bodies	Environmental/Cultural
	Consider gradual closure of Bonnet Carre Spillway to improve pallid sturgeon recovery efforts	Environmental/Cultural
	Update (weekly) consulting and culturally affiliated tribes using teleconferences and emails	Environmental/Cultural
	Follow and revise protocols for the treatment and disposition of uncovered human remains	Environmental/Cultural
	Establishing mechanisms to identify, capture, and archive environmental data	Environmental/Cultural
	Conduct LIDAR evaluation to identify potential cultural resource sites impacted by scouring	Environmental/Cultural
	Conduct consultation with SHPO and affiliated tribes as required in programmatic agreements	Environmental/Cultural
	Generate Environmental/Cultural Resource Operating Plans	Environmental/Cultural
	Complete cultural resources surveys in floodways as required by PAs or SHPOs	Environmental/Cultural
1	Document control must be an assigned, dedicated function for the MR&T Project	Data Inventory and Mgmt
2	Create a Flood Data Center	Data Inventory and Mgmt
3	Locate and inventory all historic MVD flood data	Data Inventory and Mgmt
4	Adopt a more centrally directed post-flood data capture and standardization process	Data Inventory and Mgmt
5	After data gathering is complete follow preservation processes outlined in the guidebook	Data Inventory and Mgmt
1	Provide timely and consistent mapping between districts	Communication
2	Send important information to other agencies before releasing to the public	Communication
3	Continue daily conference calls with partner agencies during emergency operations	Communication
4	Establish relationships and direct lines of communication with river industry decision makers	Communication
5	Involve Environmental NGOs in recovery efforts	Communication
6	Communicate recovery efforts to stakeholders	Communication

Operational Recommendations (cont.)		
Priority	**Recommendation**	**Component**
7	Publicize and share results of PFRs with partner agencies	Communication
	Ensure that Corps personnel are sufficiently equipped in accordance with their role	Communication
	Establish consistency between districts and other agencies (e.g., forecasts, reporting, etc.)	Communication
	Provide additional Emergency Operations training between flood events	Communication
	Continue use of android phones to send locations of sand boils, etc back to the office	Communication
	Keep Corps organization charts up to date	Communication
	Educate Corps employees and flood workers on public affairs procedures	Communication
	Expand the pool of potential Corps LNOs and train prior to next event	Communication
	Implement ProjectWise as a repository for gauge data and all pertinent flood fight info	Communication
	Use appropriate Corps chain of command	Communication
	The EOC should ensure requests for IT support are forwarded to ACE-IT at the District	Communication
	One district/division should take the lead with each state to provide “One Door to the Corps”	Communication
	Improve internal Corps information sharing	Communication
	Include public affairs section in the EOC SOP; one POC to oversee all public meetings	Communication
	Work with NWS through fusion team to establish if official NWS forecast can be released earlier	Communication
	Work between floods to better establish relationships with other governmental and NGO agencies	Communication
	Supply EOCs with multi-agency personnel to improve communication	Communication
	A Corps employee should be stationed at the US Coast Guard Command Center	Communication
	Actively participate in the Joint Information Center (and other state equivalents) during flood	Communication
	Update existing distribution lists prior to next event	Communication
	Continue communication with public but increase efforts to publicize public meetings	Communication
	Involve Public Affairs Office and Security in public meetings	Communication
	Continue use of social media for general information to the public (similar to a press release)	Communication
	Use the time between flood events to educate the public on the risks of living in a floodway	Communication
	Make Corps websites more visible	Communication

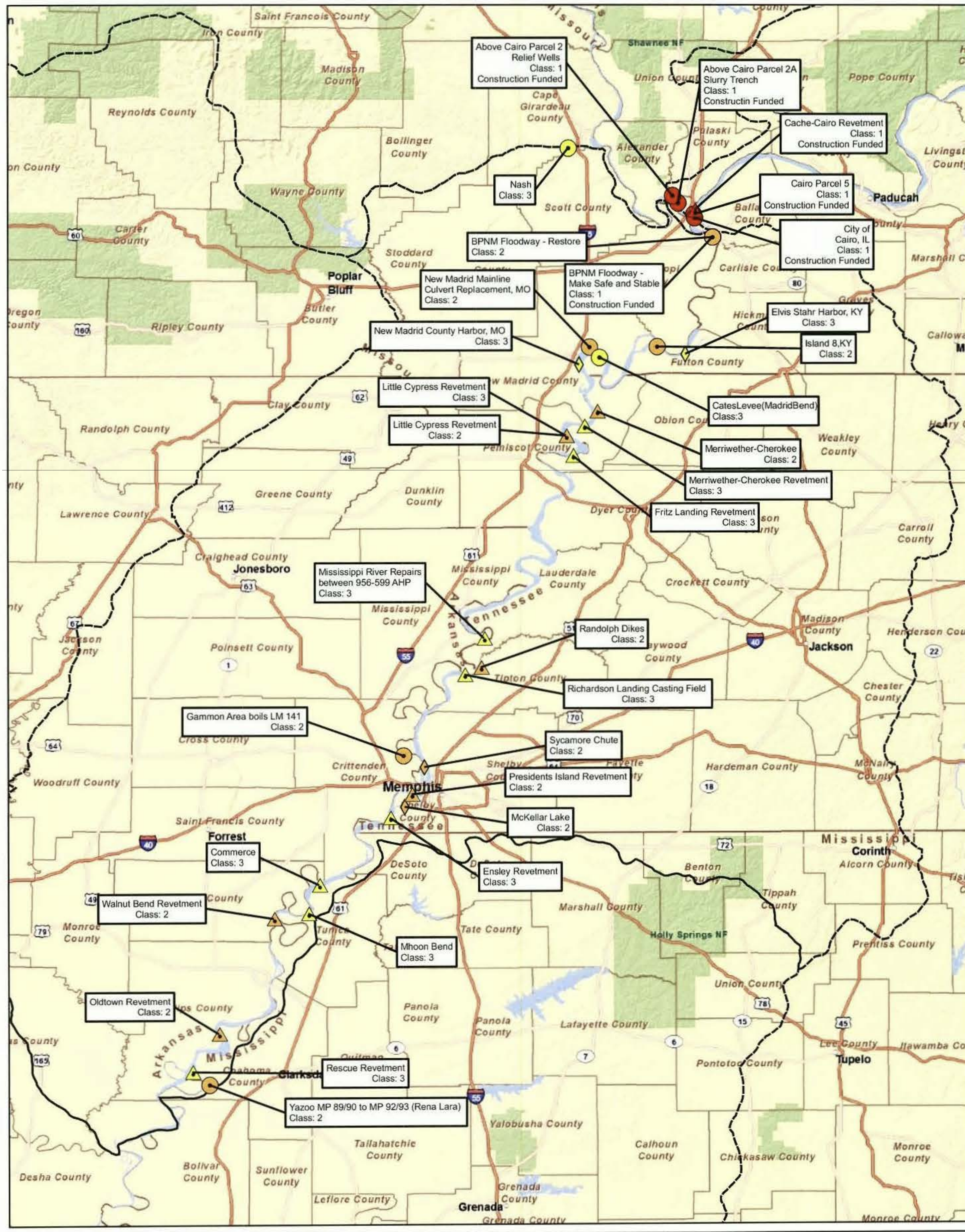
Technical Recommendations		
Priority	**Recommendation**	**Component**
1	**Evaluate the need to conduct an updated flow line study for the MR&T System**	**Overarching System**
2	Develop a HEC-RAS community model for the Mississippi River to improve forecasting	Reservoirs
1	Levee systems should be designed to be more resilient during major floods	Levees
1	Evaluate possible alternative methods of placing the BPNM floodway into operation	Floodways
1	Conduct a flowline review to examine stage-discharge relationship at Morganza	Floodways

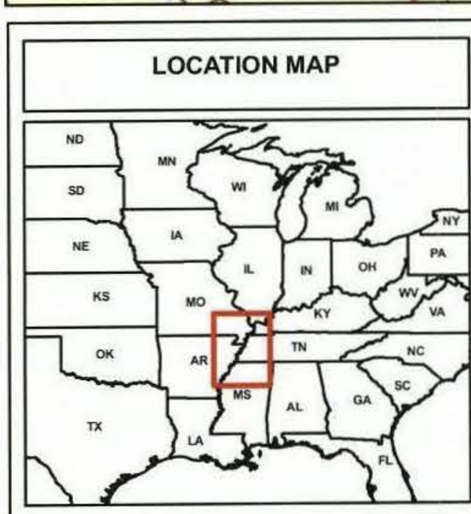
Technical Recommendations (cont.)		
Priority	**Recommendation**	**Component**
1	Assess potential operational improvements and water control manual updates for Morganza Floodway	Floodways
	Better models of the Morganza Floodway and Atchafalaya Basin should be developed	Floodways
	Better computer models of the Bonnet Carré Spillway should be developed	Floodways
	Investigate ways to permanently address railway crossing seepage at Bonnet Carré Spillway	Floodways
	Clarify computation of discharge upon which the regulation of the ORCC is based	Floodways
	Examine the pulsing flow phenomenon near ORCC	Floodways
	Operational criteria for the ORCC overbank structure should be examined to improve performance	Floodways
1	Create a hydraulic model to help inform future operation of the Yazoo Backwater	Backwaters
1	Create a hydraulic model to help inform future operation of the Red River Backwater	Backwaters
1	Perform study to assess effectiveness of onsite pumping capability at Bayou Chene	Interior Drainage
1	Assess if permanent structure proposed by Bayou Chene local sponsor enhances FRM	Interior Drainage
1	Assess effect of floodway operation, bedform changes, and secondary flow on overall flow	Channel Capacity
1	Analyze the MR&T to identify areas that may not be providing the authorized level of protection	Channel Capacity
1	Analyze complex flow patterns at Morganza, Bonnet Carré, and ORCC	Channel Capacity
	Upgrade ADCP firmware used for overbank flow measurements	Channel Capacity
	Improve documentation of ADCP self tests and moving bed tests	Channel Capacity
	Upgrade GPS receivers used with ADCPs to have at least 2 decimal minute accuracy	Channel Capacity
	Assess effect of floodway operation and bedform changes on flow measurements	Channel Capacity
	Analyze the ORCC and other areas as recommended by the Committee on Channel Stabilization	Channel Capacity
	Analyze effect of channel changes and future sedimentation trends on water surface profiles	Channel Capacity
2	Investigate methods to operate floodways that minimize environmental/cultural impacts	Environmental/Cultural
	Determine if any measures can be taken for managing nuisance species during flood events	Environmental/Cultural
	Create a web-based database or portal for standardized access to environmental data	Environmental/Cultural

US Army Corps of Engineers

Operation Watershed 2011
Mississippi River Basin Flood Repairs: MVM

03 Nov 2011





Legend

Category / Classification

- Channel Improvement, 1
- Channel Improvement, 2
- Channel Improvement, 3
- Dredging, 2
- Dredging, 3
- MRL, 1
- MRL, 2
- MRL, 3
- USACE District Boundary

0 10 20 40 Miles

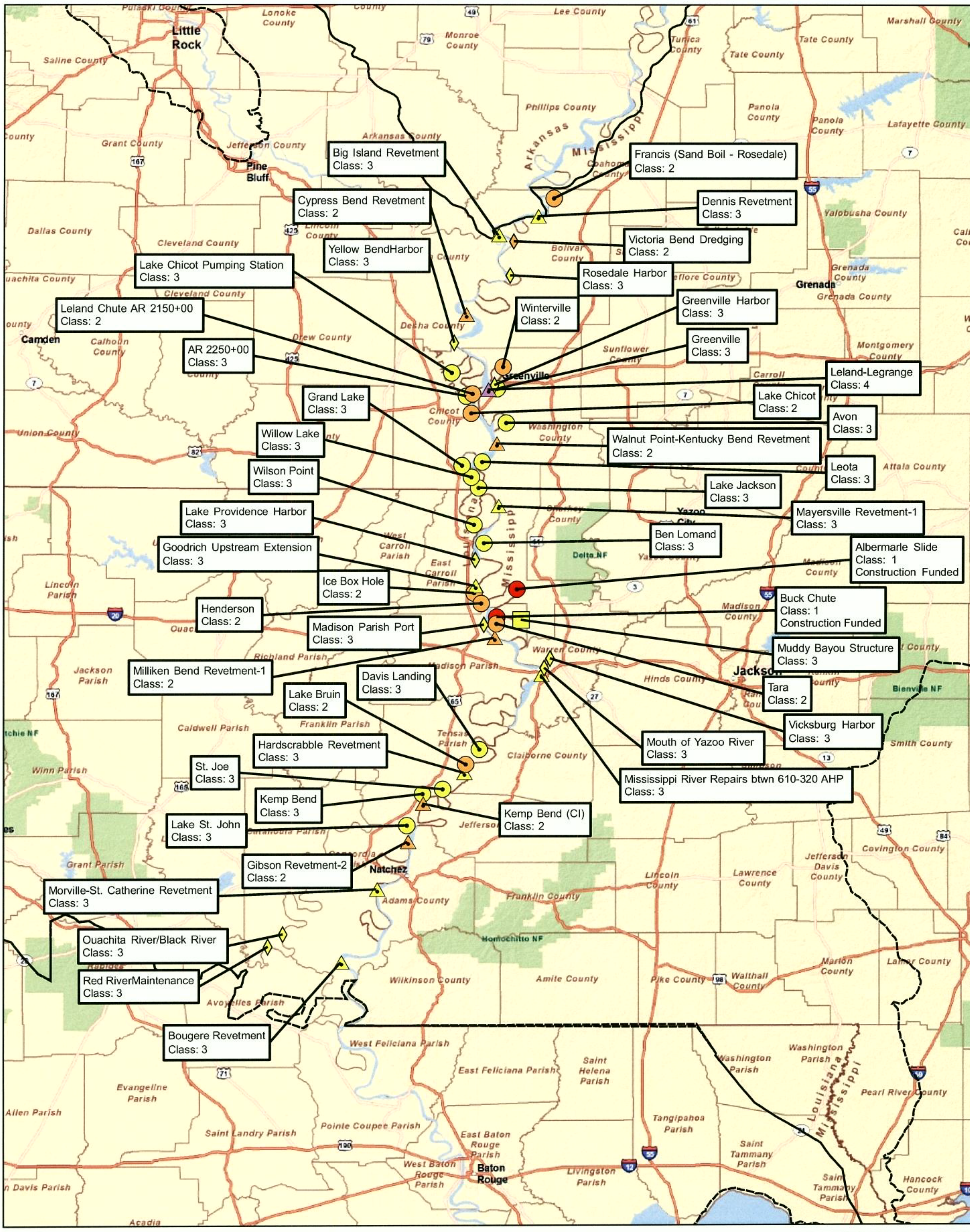
Class Defined
1 High Potential for Loss of Life (Extremely High Risk)
2 Significant Potential for Loss of Life and Economic Damage (Very High Risk)
3 High Impact to Navigation or Indirect Potential for Loss of Life (High Risk)

PLATE 1

US Army Corps of Engineers

Operation Watershed 2011
Mississippi River Basin Flood Repairs: MVK

03 Nov 2011



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Category / Classification

- Channel Improvement, 2
- Channel Improvement, 3
- Channel Improvement, 4
- Dredging, 2
- Dredging, 3
- MRL, 1
- MRL, 2
- MRL, 3
- Major Structures, 3
- USACE District Boundary

0 10 20 40 Miles

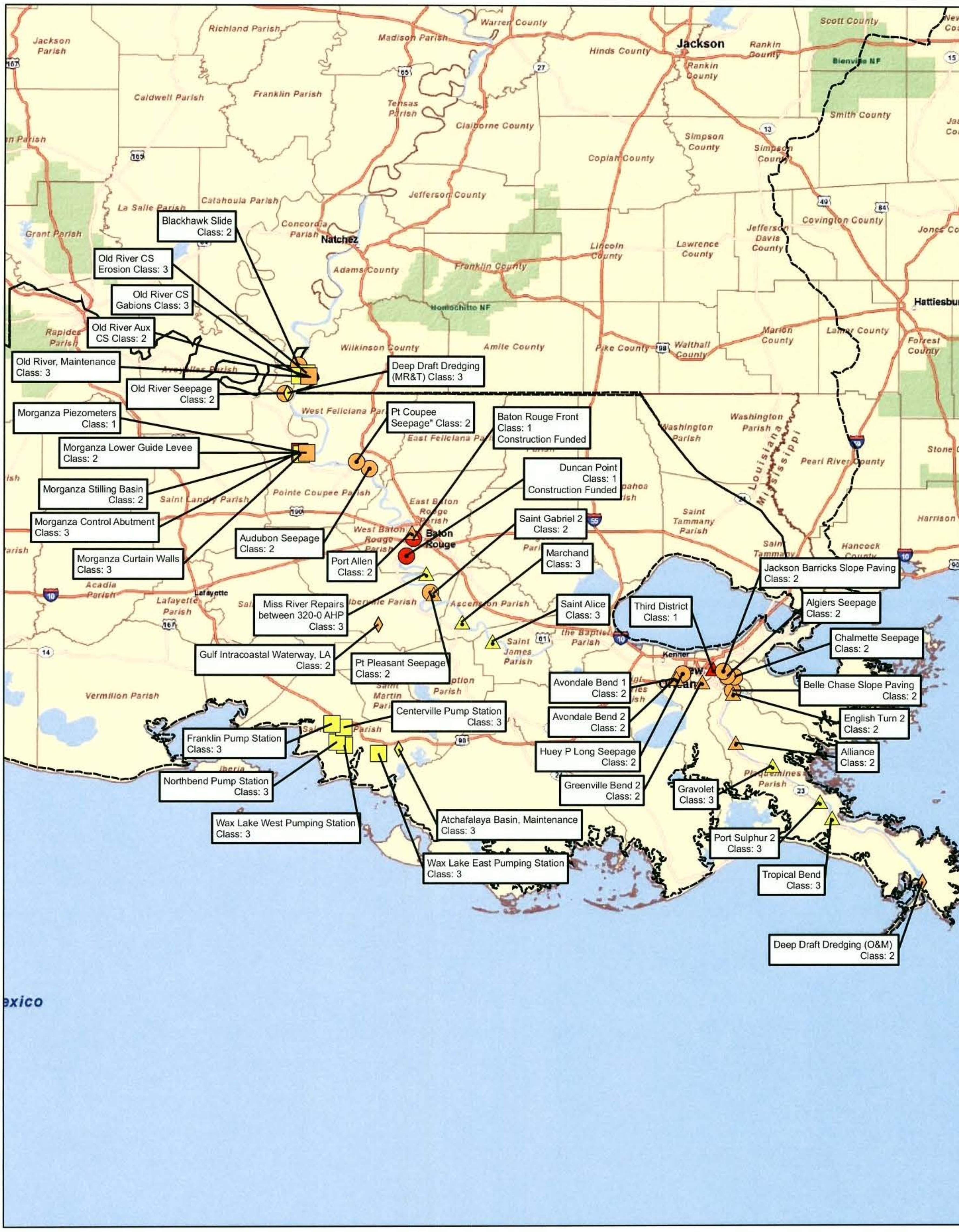
Class Defined
1 High Potential for Loss of Life (Extremely High Risk)
2 Significant Potential for Loss of Life and Economic Damage (Very High Risk)
3 High Impact to Navigation or Indirect Potential for Loss of Life (High Risk)

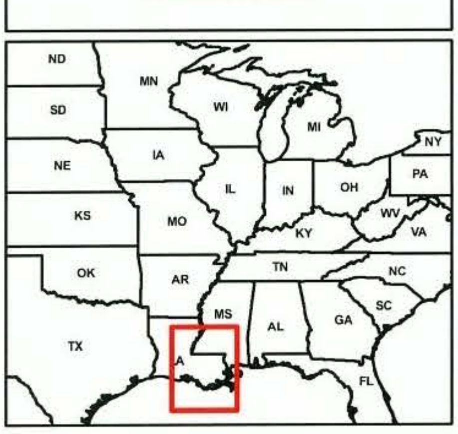
PLATE 2

US Army Corps of Engineers

Operation Watershed 2011
Mississippi River Basin Flood Repairs: MVN

04 Nov 2011





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Category / Classification

- Channel Improvement, 1
- Channel Improvement, 2
- Channel Improvement, 3
- Dredging, 2
- Dredging, 3
- MRL, 1
- MRL, 2
- Major_Structures, 1
- Major_Structures, 2
- Major_Structures, 3
- USACE District Boundary

Class Defined
1 High Potential for Loss of Life (Extremely High Risk)
2 Significant Potential for Loss of Life and Economic Damage (Very High Risk)
3 High Impact to Navigation or Indirect Potential for Loss of Life (High Risk)

N W E S

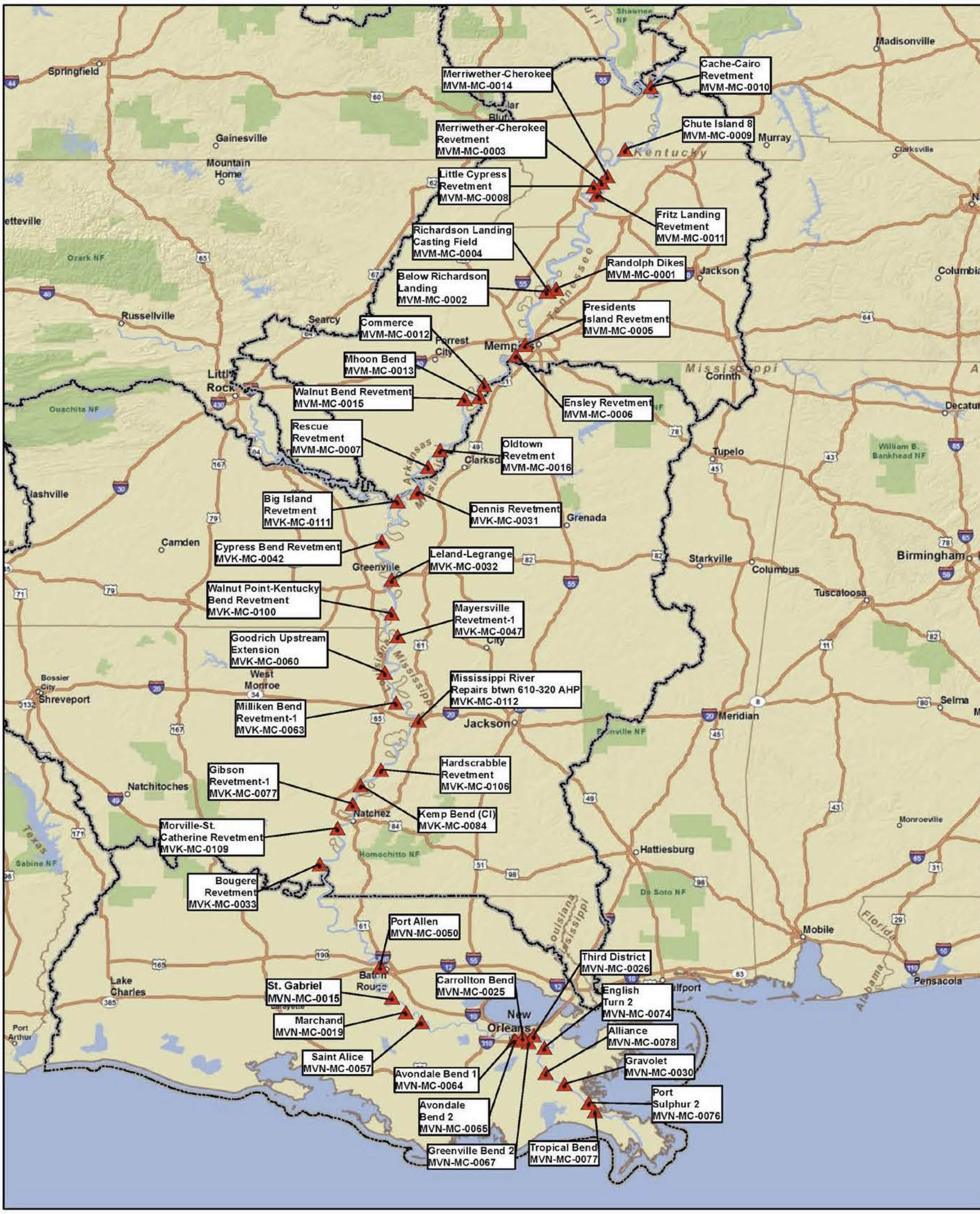
0 10 20 40 Miles

PLATE 3

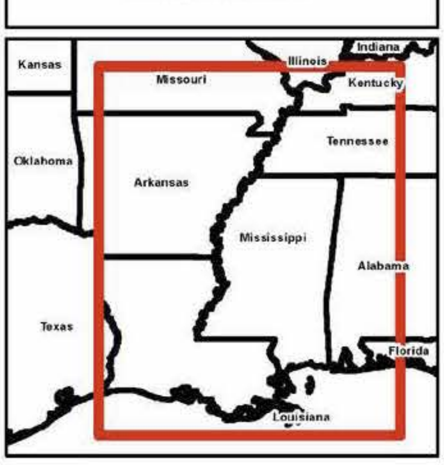
US Army Corps of Engineers

Operation Watershed 2011
MVD: Channel Improvement Critical Items

21 Feb 2012



LOCATION MAP



Legend

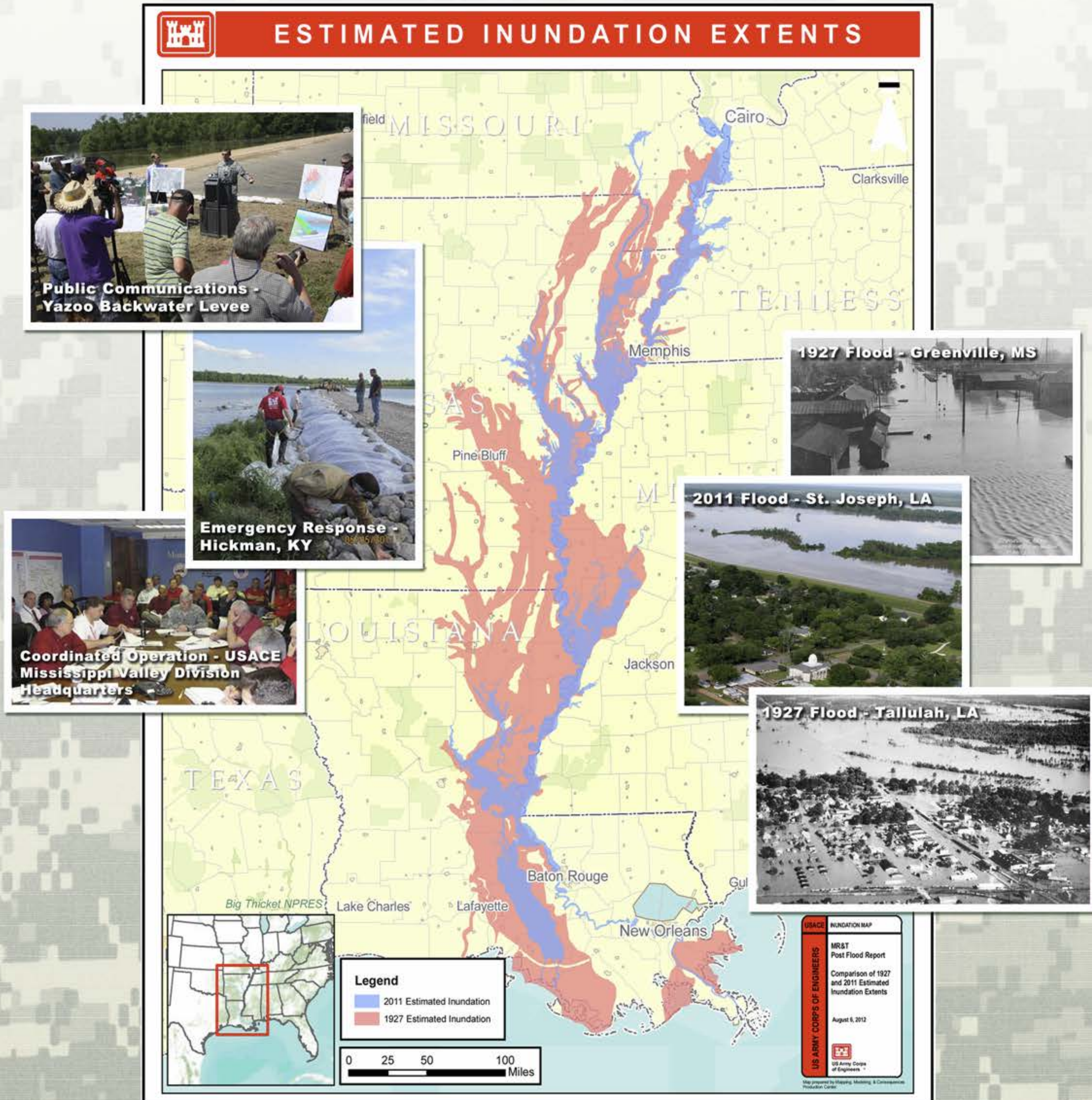
▲ Channel Improvement

District Bdy.

Feet: 0 160,000 320,000 640,000

Item rankings are as of date shown. Item ranking may change as a result of analysis and evaluation. The classification reffered to in the label was created by the Dammage Assessment Oversight Team.

PLATE 4



"SHOULD DIVINE PROVIDENCE ever send a flood of the maximum predicted by meteorological and flood experts as a remote probability but not beyond the bounds of ultimate possibility, the floodways provided in the plan are still normally adequate for its passage without having its predicted heights exceed those of the strengthened levees."

Edgar Jadwin,
Major General, Chief of Engineers
December 1, 1927 in transmitting the
Jadwin Plan to Secretary of War

Appendix M
Part 1

Wetland Reserve Program

U.S. Army Corps of Engineers
Memphis District

St. Johns Bayou and New Madrid Floodway (SJNM) Project

Wetlands Reserve Program (WRP)

Introduction:

The Wetlands Reserve Program is a voluntary program offering landowners the opportunity to protect, restore, and enhance wetlands on their property. The USDA Natural Resources Conservation Service (NRCS) provides technical and financial support to help landowners with their wetland restoration efforts. The NRCS goal is to achieve the greatest wetland functions and values, along with optimum wildlife habitat, on every acre enrolled in the program. This program offers landowners an opportunity to establish long-term conservation and wildlife practices and protection.

The WRP has been successful in restoring lands within the St Johns Bayou and New Madrid Floodway Project (SJNM) area. This has resulted in cropland being converted to other wetland uses. This trend could continue over the expected life of the SJNM Project assuming adequate Federal funding for WRP. Because of this estimates of potential future conversions had to be made to use for project impact purposes. A set of assumptions was developed and a projected timeline established. All assumptions, methodology, and resulting timeline were coordinated with and reviewed by NRCS. The following sections describe the assumptions and methodology.

Trends in WRP lands:

An analysis of data obtained from the NRCS GIS Spatial database reveals that over the past 15 years approximately 5,800 acres of cropland have been converted to WRP lands within the SJNM project area. This is a trend of approximately 155 acres per year. Most of the WRP lands (approximately 77%) have been developed within the St Johns Bayou Basin. Of these lands 94% (4,435 acres) have occurred along St Johns Bayou. While the majority of the sites are south of highway 80, a significant portion of the WRP lands in the St Johns Basin (1,256 acres) are located north of highway 80 outside of the more frequently flooded sump area. Figures 1, 2, and 3 show the actual locations of the WRP lands.

If this trend continues, future WRP lands should be expected to be developed mostly along St Johns Bayou. A very large portion of the land along lower St Johns Bayou below Highway 80 is already in woods or WRP. Therefore, absent changes in conditions that could cause tracts farther from St Johns Bayou to be offered, the potential for additional WRP lands is low in this reach below Highway 80. It is anticipated that most of the future development of WRP lands would be above highway 80. Table 1 presents the expected increase in WRP for the St Johns Basin. Over the next 50 years an additional 2,900 acres of WRP is projected to be developed for a total of about 7,400 acres (Table 2) in the St Johns Basin.

In the New Madrid Floodway, WRP has not been as prevalent. This could possibly be due to soil type as well as flood characteristics. The soil type in the lower New Madrid Floodway is a heavier clay type that is much more productive. The headwater flooding problems are also not as much an issue since the Floodway is a totally surrounded by levees which results in a smaller more defined drainage basin. NRCS has indicated that the use of Saucier soils data when restoring sites in the area indicate that the majority of WRP sites located within the St Johns Bayou Basin are in the old relic stream channels as formed by the meanderings of the Mississippi River. These typically are of a more clay and silt content and are characteristically wetter soils. These areas are commonly referred to as “valley trains” and typically are well suited for wetland restoration. Other WRP sites, when compared to Saucier soil data, located outside of the St Johns Bayou Basin are within old abandoned river channels. Again, these areas are typically more clay and silt and wetter type soils and are good wetland restoration sites (Figure 4).

A trend line analysis of the past 15 years of data shows that another 900 acres of WRP could be developed in the Floodway (Table 1). It is expected that areas by the levees in the project area would be targeted. Areas by the Mississippi River levee could be targeted because of seepage problems which cause the fields to be too wet to be profitable during high Mississippi River levels. Areas by the Setback levee could be targeted due to borrow pits and old drainage ditches or sloughs that were left during construction of the Setback levee. Over the next 50 years an additional 900 acres of WRP is projected to be developed for a total of about 2,200 acres (Table 2) in the New Madrid Floodway.

There were several assumptions made when trying to estimate future WRP lands over the next 50 years. These are listed below. In is noted that due to current Federal budget problems, it is very difficult to project growth in a program that is dependent on future Federal appropriations. In all, it is estimated that an additional 3,800 acres of WRP lands may be developed in the general project vicinity for a total of 9,600 acres (Table 2).

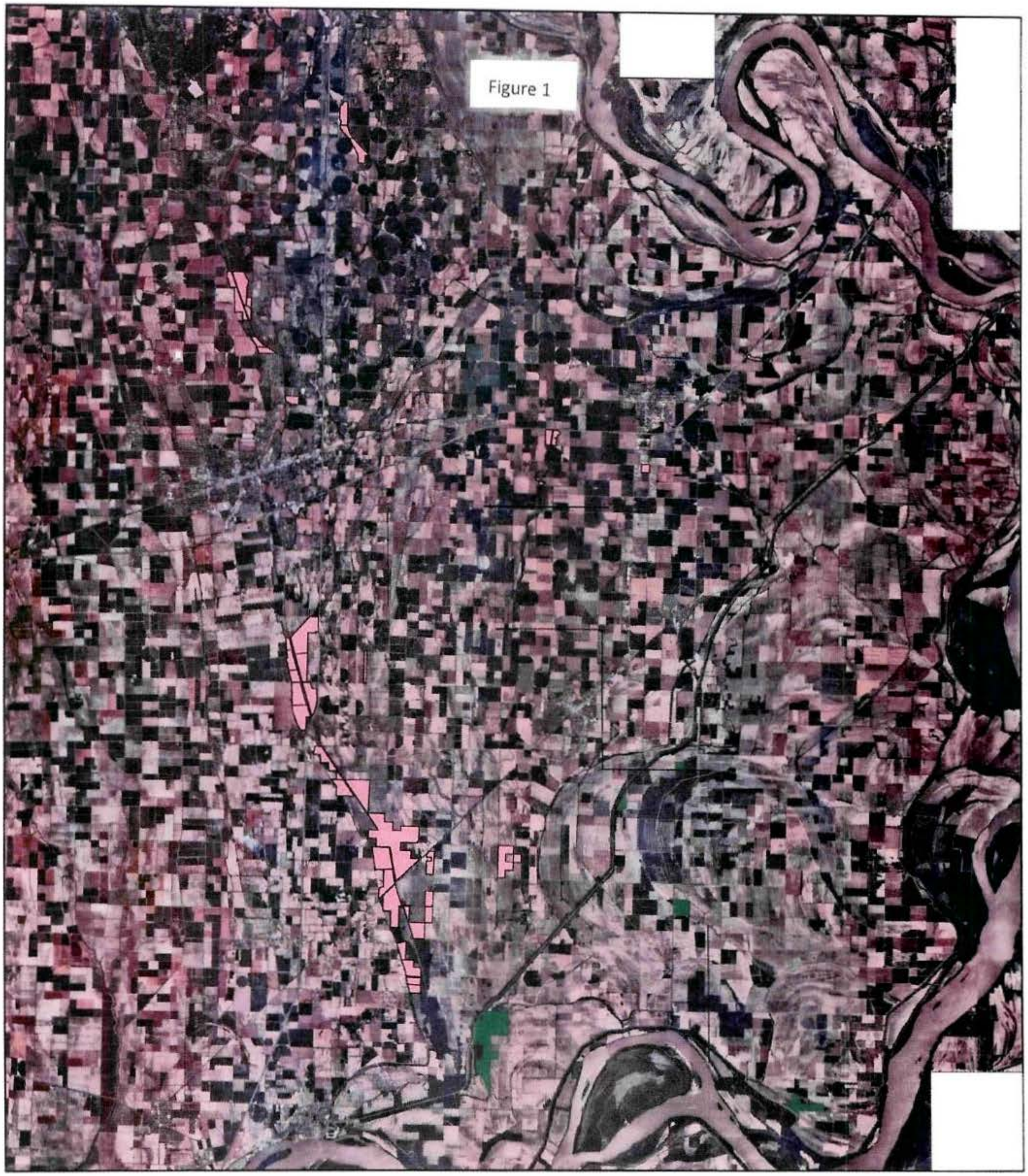
<u>Assumptions Used for Projecting WRP Lands in Project Area:</u>

1. Much of the increase in WRP lands is located out of the “backwater” or “sump” area. Of the total 4,435 acres in the St Johns Bayou Basin, 1,256 are located above Hwy 80.
2. The increase in WRP lands within the St Johns Basin appear to be influenced more by “headwater” flooding than by “backwater” flooding.
3. It appears that the increase in WRP along St Johns Bayou is also influenced by soil type. Much of the land appears to be wetter, less productive with lower yields due to factors other than flooding.
4. Most of the WRP lands are located along St Johns Bayou, 4,164 of 4,435 or about 94% of the WRP acreage in the St Johns Bayou Basin.
5. Very little of the WRP lands are located in the New Madrid Floodway 1,346 acres.

6. The WRP lands located in the Floodway appear to be influenced by seepage from the Mississippi River during high river stages and soil types which are wet and hard to farm. They also appear to be influenced by construction activities associated with construction of the Setback levee for the Birds Point-New Madrid Floodway Project.
7. Over the past 15 years WRP lands in the project area have increased about 155 acres per year.
8. Prorating the 155 acre increase per year between the basins yields an increase of about 36 acres per year in the New Madrid Floodway and 119 acres per year in the St Johns Bayou Basin.
9. The trend in the project area in the lower St Johns Bayou Basin can probably not be sustained as targeted areas along St Johns Bayou Basin are converted. All additional WRP lands south of Hwy 80 are expected to occur within 10 years. Any further increases are expected to be along St Johns Bayou upstream of the project area (north of Hwy 80).
10. The trend in WRP lands can probably be maintained in the New Madrid Floodway with an increase of approximately 900 acres after 25 years and remain constant thereafter.
11. Future WRP lands in the Floodway are projected to be located in wet areas along the Mississippi River levee within seepage areas, along the Setback levee, and in old Mississippi River scars. NRCS may start targeting "best suited priority areas" per data like Saucier in the future to assure quality sites are enrolled.
12. These trends can only be sustained with continued WRP funding levels. Current Federal budget difficulties could cause these trends to slow. Because of these difficulties projections were made for 25 years with levels remaining constant for later years.
13. Agricultural prices have been very unfavorable for WRP conversion in the last year or two. Higher agricultural prices have caused crop production to be more profitable. If this trend continues the rate of WRP conversion should slow.
14. Voluntary programs such as the Migratory Bird Habitat Initiative will help to ensure existing WRP sites are maintained to ensure they perform as originally designed.

Future WRP Projections /Adjusted Stage Area Curves:

USACE assumed a linear relationship for acres enrolled at a 1-foot elevation contour, as well as, a linear relationship with the type of land cover (70% forest, 20% herbaceous, 10% open water based on feedback provided by NRCS). For planning purposes, it was assumed that the lower elevation lands would be enrolled in WRP first; then, the available lands at the next higher elevation until all projected WRP were accounted. Adjusted stage area curves were developed for the St. Johns Basin (Table 3) and New Madrid Floodway (Table 4) to reflect projected future WRP lands.



SJNM WRP Lands

Legend

New Madrid WRP

St. Johns WRP

SJNM WRP Lands

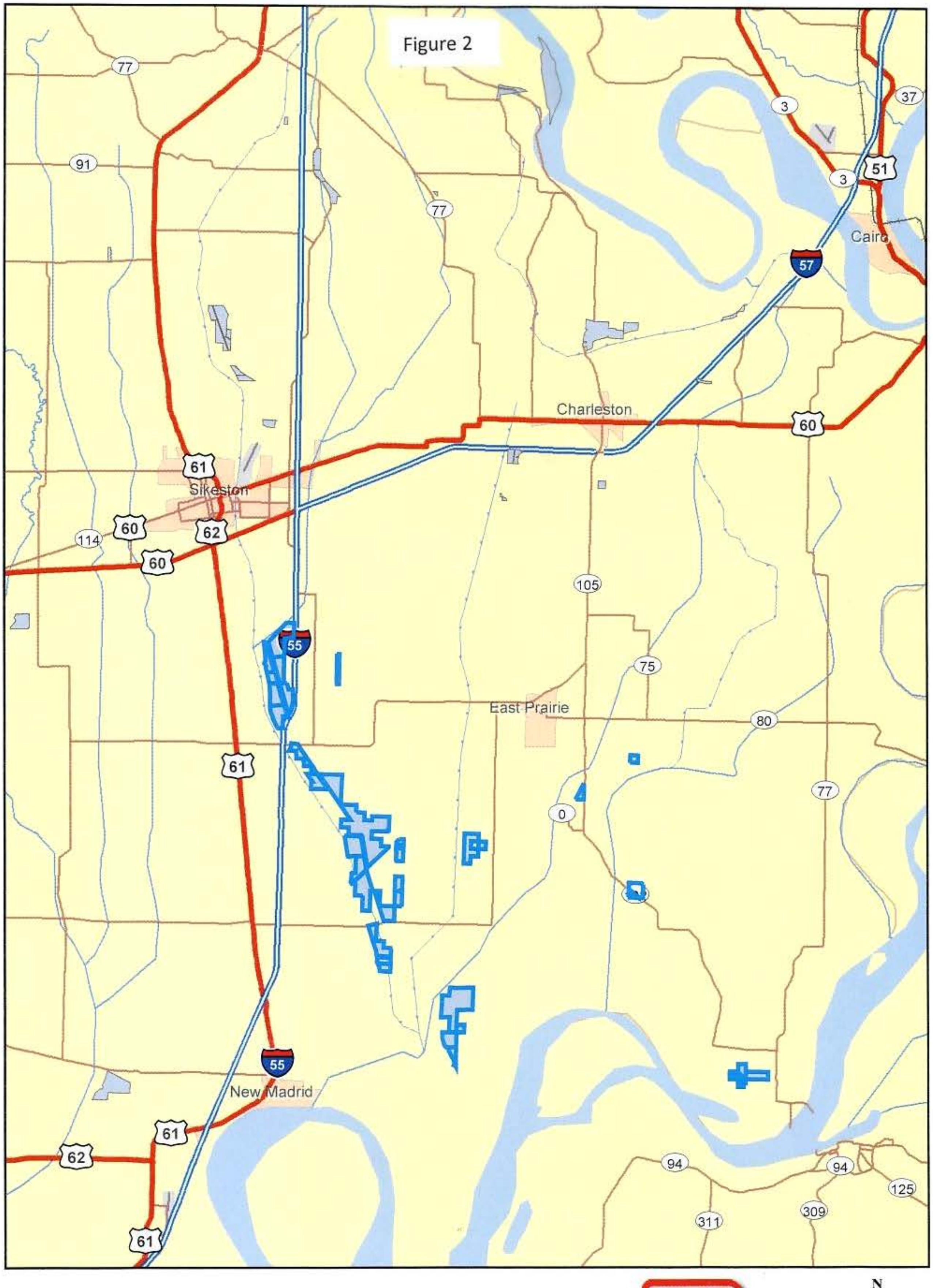
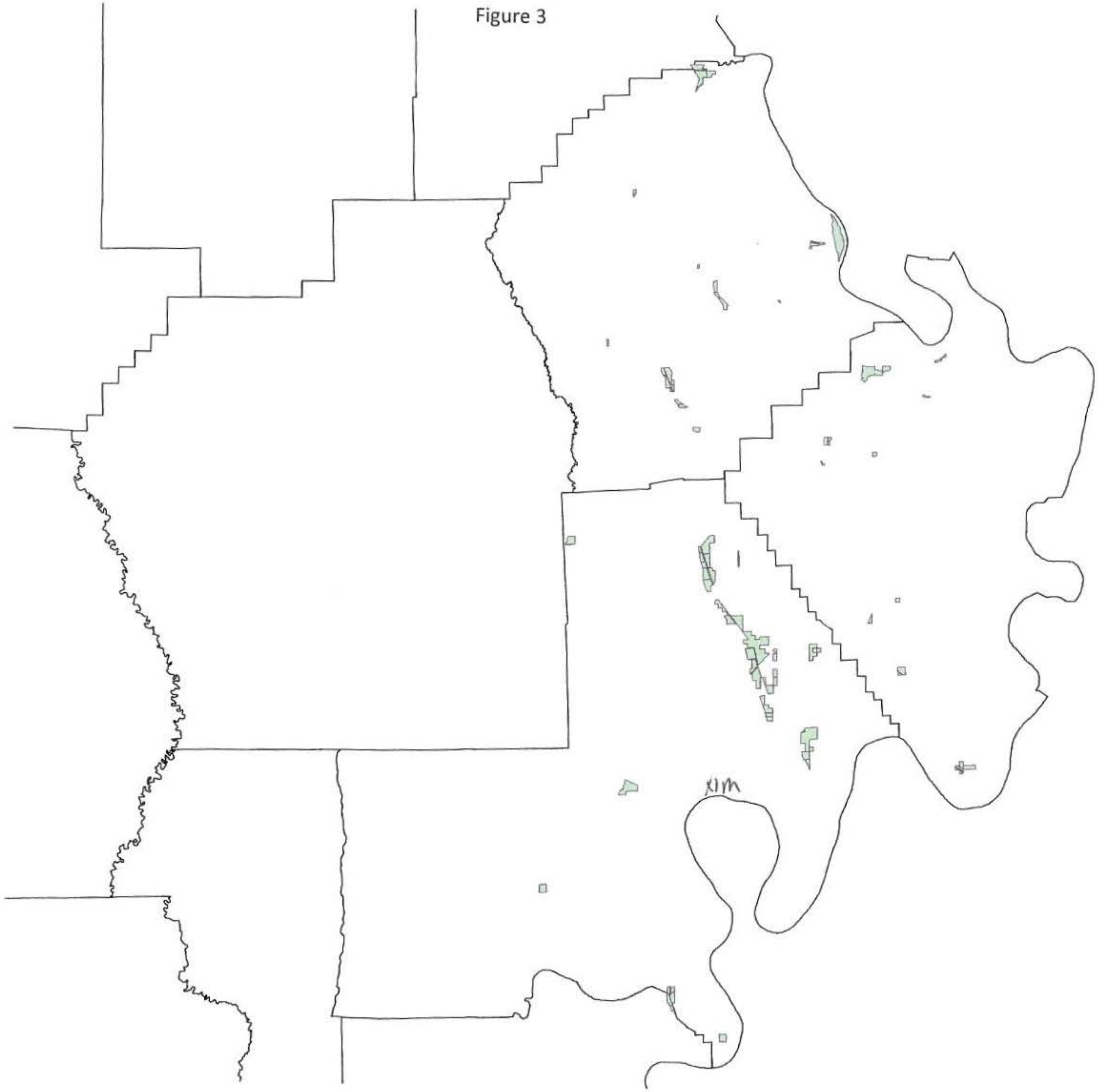


Figure 3



SJNM - WRP sites compared to Saucier data

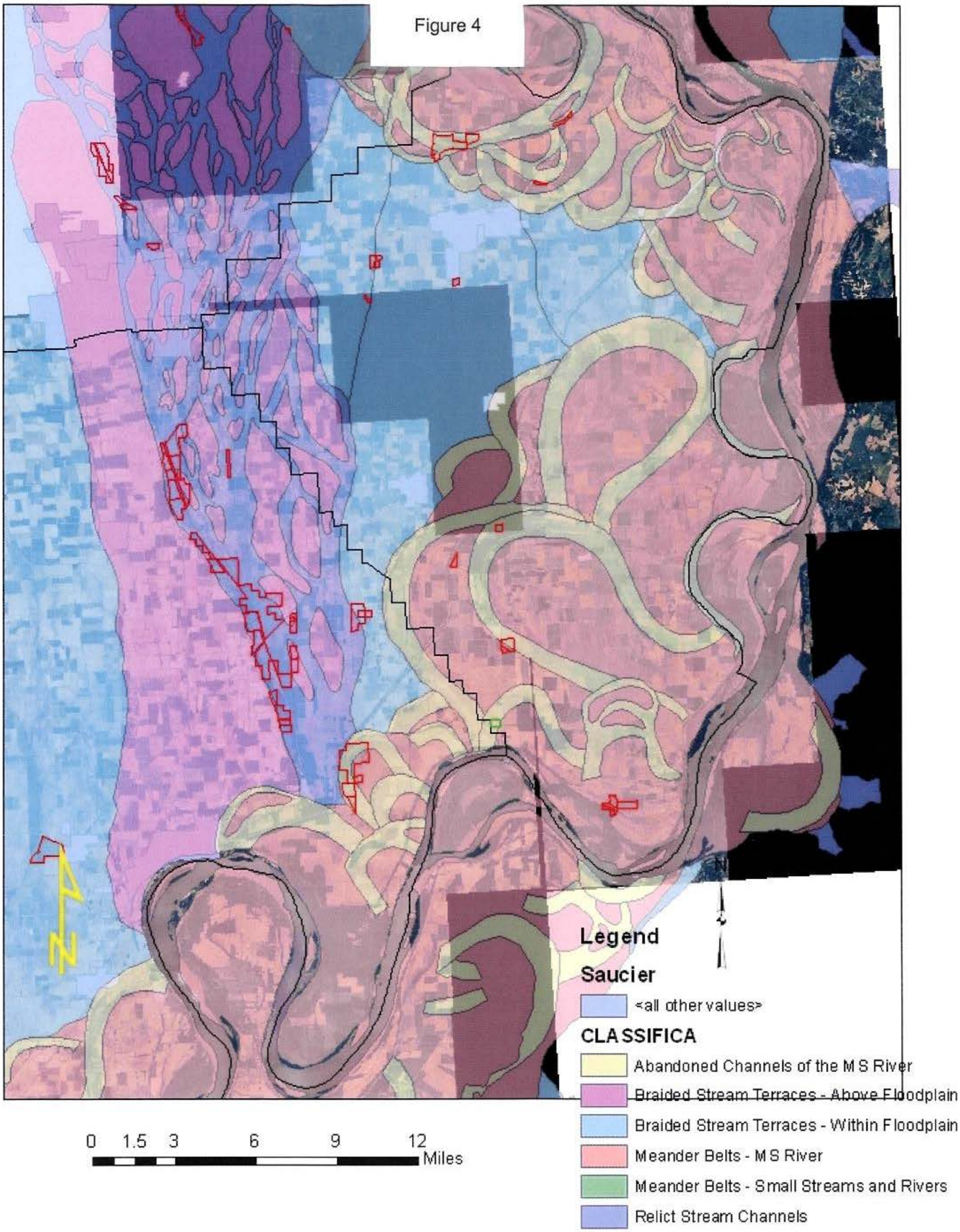


Table 1
Projected Increase in WRP Lands
St Johns Bayou and New Madrid Floodway

Area	Present (2010)	Acres /Year	Years in Future 10	15	20	25	50
Floodway	1,346	36.05	400	600	800	900	900
Bayou Basin	4,435	118.81	1,100	1,700	2,300	2,900	2,900
Below Hwy 80	3,179	85.15	800	800	800	800	800
Above Hwy 80	1,256	33.66	300	900	1,500	2,100	2,100
Total	5,781	154.86	1,500	2,300	3,100	3,800	3,800

Table 2
Total WRP Lands (Actual Acres with Projections)
St Johns Bayou and New Madrid Floodway

Area	Present (2010)	Acres /Year	Years in Future 10	15	20	25	50
Floodway	1,346	36.05	1,700	1,900	2,100	2,200	2,200
Bayou Basin	4,435	118.81	5,600	6,200	6,800	7,400	7,400
Below Hwy 80	3,179	85.15	4,000	4,000	4,000	4,000	4,000
Above Hwy 80	1,256	33.66	1,600	2,200	2,800	3,400	3,400
Total	5,781	154.86	7,300	8,100	8,900	9,600	9,600

Table 3									
ST. JOHNS - Future with WRP									
Elevation	Agriculture	Developed	Fallow	Forest	Herbaceous	Open Water	Pasture	Scrub/Shrub	Total Acerage
281 and below	250.3	13.1	0.0	335.9	10.6	100.2	N/A	N/A	710.1
282 and below	266.2	15.4	0.1	387.8	12.2	100.3	0.0	N/A	782.0
283 and below	282.0	17.0	0.9	446.2	13.9	100.7	0.1	N/A	860.9
284 and below	1,568.2	31.7	5.6	877.1	43.3	158.6	0.5	N/A	2,685.1
285 and below	1,625.9	34.0	11.1	1,006.2	47.3	161.2	0.6	N/A	2,886.2
286 and below	1,686.7	41.8	38.9	1,572.0	98.3	204.3	0.8	N/A	3,642.8
287 and below	2,098.7	56.8	88.7	2,400.2	172.9	282.8	1.1	N/A	5,101.2
288 and below	2,290.2	65.4	152.2	2,896.4	222.4	315.1	1.2	N/A	5,942.9
289 and below	2,581.6	84.7	195.5	3,305.7	264.9	339.8	1.4	N/A	6,773.6
290 and below	3,506.0	126.2	233.2	3,931.3	306.6	376.1	2.9	N/A	8,482.2
291 and below	6,026.0	211.9	287.1	4,581.6	383.5	406.8	7.4	N/A	11,904.3
292 and below	9,162.7	330.1	305.0	5,212.1	449.9	440.1	12.9	N/A	15,912.8
293 and below	10,990.4	417.2	313.5	5,563.7	495.8	458.0	23.5	N/A	18,262.2
294 and below	12,530.1	479.2	316.7	5,810.2	525.0	469.6	44.6	N/A	20,175.5
295 and below	14,439.7	548.3	319.2	6,045.1	546.0	478.9	111.3	N/A	22,488.5
296 and below	20,623.5	840.4	321.4	6,604.4	593.4	495.0	483.2	N/A	29,961.4
297 and below	28,314.0	1,336.6	325.0	7,264.0	675.2	520.6	938.9	N/A	39,374.3
298 and below	30,684.6	1,515.9	327.7	7,636.8	708.4	535.1	1,073.8	0.0	42,482.5
299 and below	32,628.1	1,676.2	329.6	7,886.4	724.9	542.8	1,194.4	0.3	44,982.8
300 and below	34,680.1	1,852.1	333.3	8,072.3	730.8	546.2	1,273.9	0.8	47,489.4

Table 4

NEW MADRID - Future with WRP

Elevation	Agriculture	Developed	Fallow	Forest	Herbaceous	Open Water	Pasture	Scrub/Shrub	Total Acerage
280 and below	0.0	0.7	5.7	341.6	102.0	68.8	0.1	0.0	518.9
281 and below	0.0	1.6	6.0	486.7	263.5	82.0	0.3	0.0	840.1
282 and below	0.0	2.5	6.4	680.1	504.4	106.9	0.4	0.0	1300.8
283 and below	136.7	5.6	7.2	855.5	627.3	131.7	0.5	0.0	1764.5
284 and below	555.6	10.1	10.5	990.1	649.9	202.0	0.6	0.0	2418.8
285 and below	1112.9	22.9	30.1	1246.6	661.9	274.3	0.7	0.2	3349.7
286 and below	2264.7	42.0	91.4	1827.9	687.9	370.8	0.9	0.6	5286.2
287 and below	4150.2	71.6	154.6	2879.6	730.0	489.1	1.0	1.0	8477.1
288 and below	6922.6	117.1	183.8	3905.2	786.1	588.9	1.3	1.5	12506.5
289 and below	10674.4	170.2	192.1	4770.5	806.2	633.4	1.7	1.5	17250.0
290 and below	14719.9	214.6	197.1	5529.5	819.8	668.3	2.2	1.5	22153.0
291 and below	19040.1	280.2	200.3	5987.7	839.9	683.8	3.7	1.6	27037.4
292 and below	24219.6	392.0	202.5	6410.3	855.5	698.8	6.0	1.6	32786.3
293 and below	29537.4	552.3	203.9	6948.6	875.9	709.0	8.9	1.6	38837.6
294 and below	34832.5	730.4	205.6	7482.3	901.2	722.2	13.1	1.7	44889.0
295 and below	39771.8	946.6	207.1	7883.1	909.1	738.1	20.2	1.7	50477.7
296 and below	44341.4	1177.9	208.0	8210.8	915.7	765.8	28.0	1.8	55649.5
297 and below	49241.4	1432.3	209.0	8591.8	921.8	774.4	40.7	5.9	61217.1
298 and below	53826.6	1718.9	209.4	8906.5	934.1	781.0	63.0	9.1	66448.6
299 and below	59321.9	2046.1	211.0	9192.2	938.8	789.1	83.1	9.2	72591.4
300 and below	64784.2	2410.9	211.7	9457.1	942.8	794.9	104.6	9.2	78715.4

Appendix M
Part 2

WETSORT

U.S. Army Corps of Engineers
Memphis District

Determination of Wetland Elevation
from Daily Water Surface Elevations
Using the Computer Program WETSORT

US Army Corps of Engineers, Memphis District
March 23, 2010

INTRODUCTION

This document describes how the computer program WETSORT can be used to determine a wetland elevation from daily water surface elevations. In addition to this Introduction section, the document contains an Instructions for Running WETSORT section, a References section, and Appendices A through F. An example problem is included, illustrating a typical application of WETSORT for a stream channel and floodplain in the southeast United States.

NRCS Technique

The method used in WETSORT has been published by the USDA National Resources Conservation Service in the *Engineering Field Handbook*, Chapter 19 (1997). Twenty pages selected from Chapter 19 are included for reference in Appendix-A. WETSORT is simply a utility program to quickly and accurately process many years of water surface elevation data according to the NRCS method. WETSORT is only used to analyze surface water--not shallow groundwater or topsoil moisture.

Program Origen

WETSORT was written in the FORTRAN 77 language by the US Army Corps of Engineers, Vicksburg District. The WETSORT source code of the version used in the example problem is listed in Appendix-F. The source code is brief, partly because the computations are simple, and partly because the program calls subroutines from a library to deal with dates and to retrieve data from the DSS file.

WETSORT obtains all of its run control input from keyboard entries, but obtains the daily water surface elevation data from a binary file in the Corps HEC-DSS format. The Data Storage System (DSS) is the Corps' water data management software. WETSORT produces an ASCII output file.

WETSORT dates back to at least 1995. A windows feature dating back to at least 1997 provides an easy way for the user to input run control data to WETSORT. Although the windows version is convenient, it is not as versatile as the DOS version used in this document to work the example problem. The version used to work the example problem allows any flooding duration to be input. In contrast, the windows version is hard-coded to calculate durations that are 5 and 12.5 percent of the growing season, rather than to accept a user-determined duration.

Concept

Ideally, wetlands are occupied by species of plants that tolerate standing water, or moist soil, or occasional flooding lasting several continuous days during the growing season. Since WETSORT is not applicable to evaluating moist soil or shallow groundwater, the discussion here will focus only on the rise and fall of water surface elevations in a wetland over time.

In a wetland, the general absence of non-water tolerant plant species below a certain elevation is associated with a history of flooding at approximately that elevation during the growing season. The flooding lasts long enough at that elevation to kill non-water tolerant plants. The number of days of flooding sufficient to kill non-water tolerant plants is called the duration. During a single growing season, the highest elevation continuously flooded for the lethal duration is the wetland elevation for that growing season, and also for that calendar year. Of course, over a period of years, the annual wetland elevation varies randomly about some representative elevation.

In Figure 1 below, the dashed water surface elevation represents such a representative wetland elevation. All vegetation rooted below the dashed line is water tolerant. In this figure, the low flow elevation of the stream is somewhat lower than the wetland elevation. Of course, there are degrees of water tolerance among plants, and it is the role of the biologist to identify the marker species for an analysis and the duration to be used in a WETSORT analysis. The bell curve to the right of the figure represents the distribution of annual wetland elevations.

Since flooding varies randomly from year to year, the annual wetland elevation varies randomly also. WETSORT facilitates the identification of a median wetland elevation determined from a multi-year analysis period. The median wetland elevation is considered representative for characterizing the long-term average wetland elevation at a site.

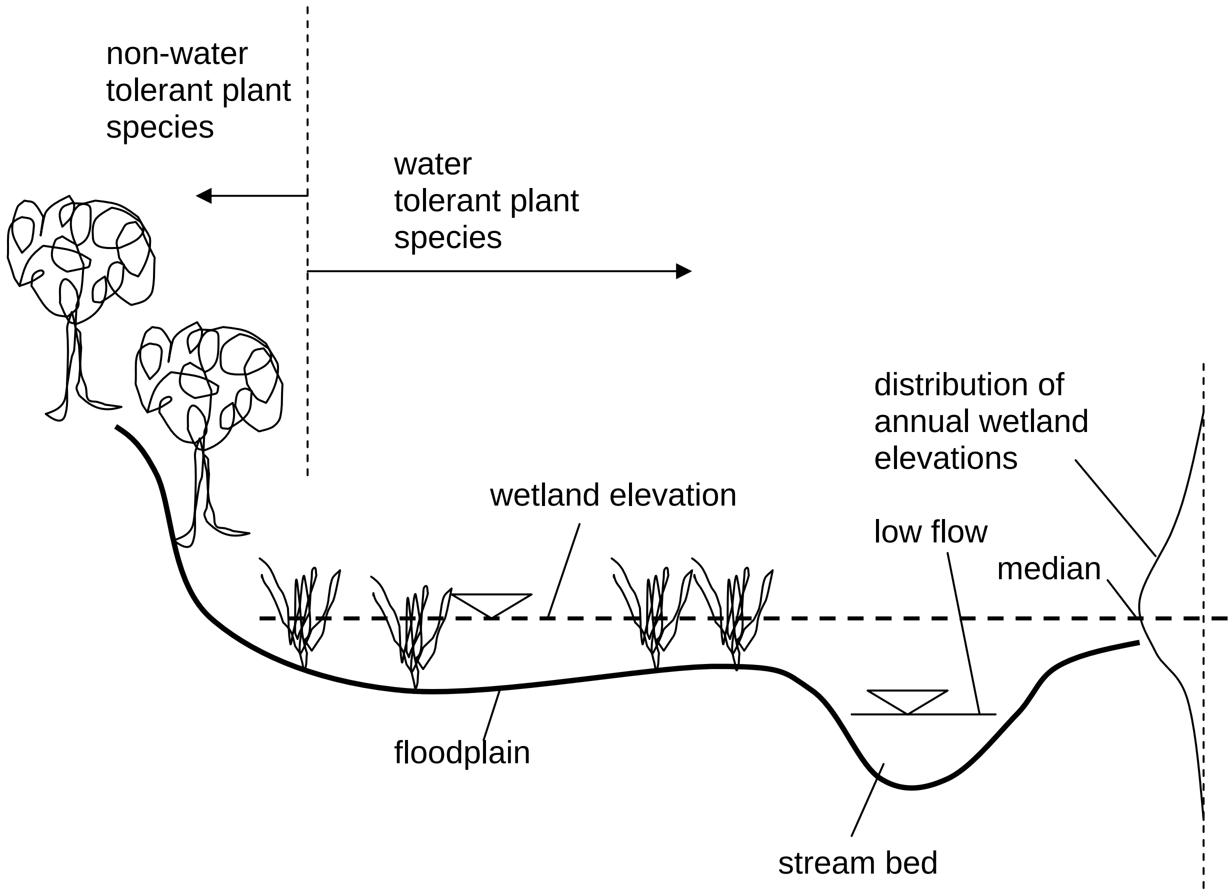


Figure 1. Section of Stream and Floodplain

The growing season is the only part of the year for which WETSORT analyzes water surface elevations. The beginning and ending dates of the growing season must be specified by the user. In Figure 2 the growing season begins on 20MAR and ends on 10NOV (a total of 236 days), and this is the growing season used in the example problem.

In some analyses a flat number of days, such as 15, for example, is specified as the duration--this is how the example problem is set up. However, in some project analyses, percentages of the growing season have been calculated and rounded to the nearest day. For example, percentages of 5 and 12.5 percent have been used in projects, with the intent of bracketing a zone of elevations that may, or may not, be wetlands. Land below the 12.5 percent elevation has been considered definitely a wetland. Land above the 5 percent elevation has been considered definitely not a wetland. The elevation zone between the 5 and 12.5 percent elevations was to be checked to determine if it were a wetland.

If the 5 and 12.5 percent durations had been used in the example problem, the durations would have been 12 and 30 days. For 5 percent of the 236-day growing season, 11.8 days can be rounded to 12 days. For 12.5 percent of the 236-day growing season, 29.5 days, can be rounded to 30 days.

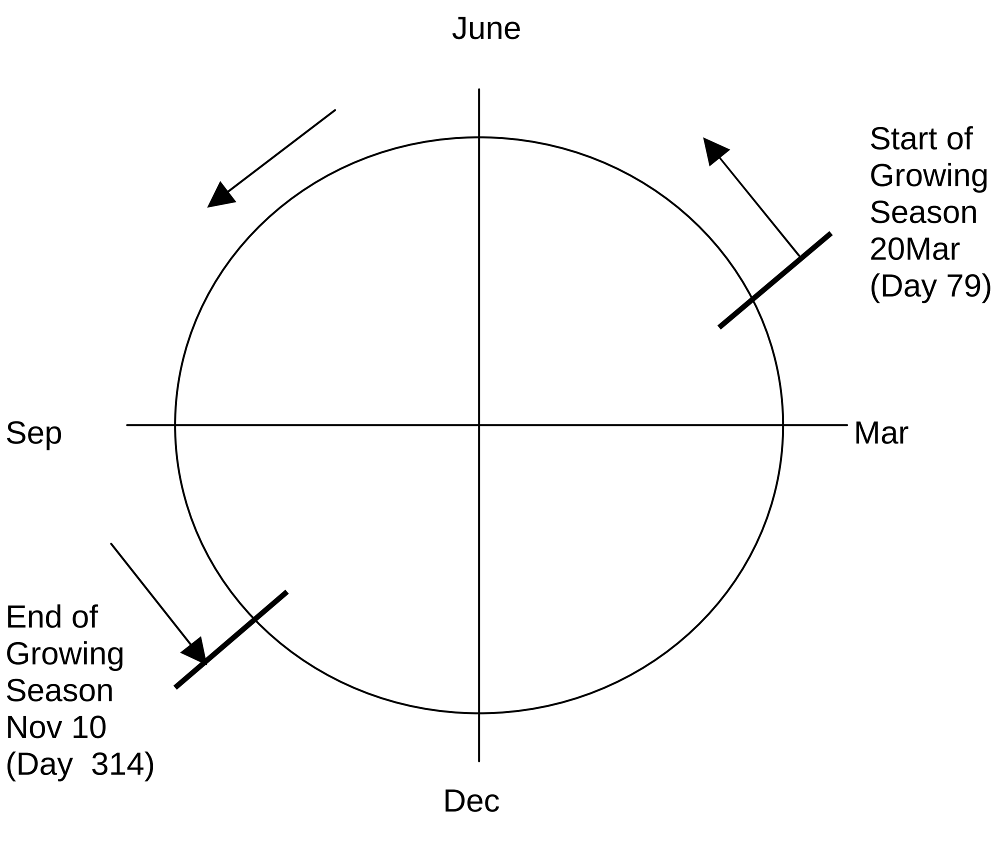


Figure 2. Example Growing Season
20Mar to 10Nov, Inclusive (236 Days)

INSTRUCTIONS FOR RUNNING WETSORT

Version

The instructions in this section apply to a 1995 version of WETSORT the Memphis District received from the Vicksburg District. The characteristics of the source code and executable files are listed in Table 1, below. This version of WETSORT runs in the Microsoft Windows Command Prompt window. Although not a windows application, the program is very easy to run.

Table 1. WETSORT File Characteristics

File Name	File Size KB	Date	Time
WETSORT.FOR	11	11/9/1995	3:40 pm
WETSORT.EXE	467	11/9/1995	3:40 pm

File Location

The executable file WETSORT.EXE and the DSS file containing the daily stage data should be in the same folder, or directory, of the computer. For example, the two files could be placed in a folder named "WET" under the C: drive of the computer, i.e., "C:\WET." WETSORT will write its output file into this same folder.

Command Prompt "DOS" Window

It is possible to start WETSORT by double-clicking the WETSORT.EXE file in Windows Explorer, which will bring up the DOS window. However, after making the necessary entries from the keyboard, the DOS window may disappear as the program runs.

Since it is desirable to see the trace of the program run in the DOS window, it is better to first open the DOS window and then run WETSORT, which does preserve the trace of program execution. The DOS window will remain open after program execution. The DOS window can be opened by clicking the sequence *Start, Programs, Accessories, Command Prompt*. The traditional DOS commands are used to move to the folder where WETSORT.EXE and the DSS file are. Placing the folder immediately under the C: drive makes this maneuver easy, as shown in the commands listed below.

Command Prompt Window
(Keystrokes are in **bold**)

U:\>	Suppose computer is initially set on a drive named "U".
U:\> **C: (enter)**	This changes from the U drive to the C drive.
C:\>	Computer is now set to C drive.
C:\> **CD WET (enter)**	This changes to the folder named WET.
C:\WET>	Computer is now set in WET folder.
C:\WET> **WETSORT (enter)**	Executes the WETSORT program.

Keyboard Input

All of the input used to control the execution of WETSORT is provided via the keyboard. The DSS input file only provides daily water surface elevation data.

The DOS window trace of the example WETSORT run is provided in three pages of screen shots located in Appendix-C. Screen shot page 1 of 3 records the program prompts and keyboard entries for the example problem. The very first line on page 1 of 3 is the execution command line, and shows that for this run the files were located in a folder U:\HUNTR\~wetsort>.

The first prompt is for the output filename. In response, WETEXMPL.OUT was entered.

The second prompt is for the stream name. In response, NOWHERE RIVER was entered.

The third prompt is for the gage location. In response, LOST HIGHWAY BRIDGE was entered. It is important to realize that "gage location" simply means any identifiable location, since WETSORT can be used on either historical gage data or synthetic input derived from numerical models.

The fourth prompt is for the starting year of the WETSORT analysis. In response, 1971 was entered.

The fifth prompt is for the ending year of the WETSORT analysis. In response, 1990 was entered, for a total of 20 years to be analyzed.

The sixth prompt is for the starting month of the growing season. In response, 3 was entered, representing March.

The seventh prompt is for the starting day of the growing season. In response, 20 was entered, representing 20March.

The eighth prompt is for the ending month of the growing season. In response, 11 was entered, representing November.

The ninth prompt is for the ending day of the growing season. In response, 10 was entered, representing 10November.

The tenth prompt is for the number of days of "five percent duration." In response, 15 was entered. Note that 15 is not five percent of the 236 day growing season (instead, 12 days is approximately five percent). It is important to realize that the phrase "five percent" is simply a title. The phrase "five percent" reflects an expectation by the programmer that the number of days input would indeed amount to five percent of the growing season, but actually any integer value ranging from 1 to the total number of days in the growing season is permissible.

The eleventh prompt is for the gage zero. In response, a 0.00 was entered. The gage zero is a constant that is added to all the daily water surface values. The gage zero allows stage data to be converted to sea level elevations. In this example, the DSS values are stages, rather than elevations, but for simplicity the gage zero was left at zero, which amounts to no conversion. Therefore, in the output file values in the stage and elevation columns are identical.

The twelfth prompt is for the DSS filename. In response, WETEXMPL.DSS was entered. It is important to type the full filename, including the extension ".DSS".

The thirteenth prompt is for the DSS pathname. In response, the path /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAGE//1DAY/PUB/ was entered. The path must begin and end with the forward slash, "/". Also, the parts must be separated by the forward slash. NOWHERE RIVER is Part-A. LOST HIGHWAY BRIDGE is Part-B. STAGE is Part-C. Part-D is to be omitted, but the double slash is necessary. 1DAY is Part-E. PUB is Part-F. Note that Part-C must either be STAGE or ELEV. Also, Part-E must be 1DAY. Parts A, B, and F are arbitrary names.

After the DSS pathname has been typed-in and the enter key struck, the program runs. If there are no problems with the input, records of data being read from the DSS file will be traced to the DOS window. This usually takes only a fraction of a second. In this program run, the trace of DSS records fills most of screen shot page 1 of 3, all of page 2 of 3, and virtually all of the page 3 of 3. Each block of text reflects one year of data being retrieved from the DSS file. At the bottom of page 3 of 3 is the phrase "Stop-Program terminated", which is the sign of a successfully completed run. The command prompt widow returns to the prompt for the folder, "U:\HUNTR\~wetsort>".

WETSORT does not give the user opportunities to go back and correct entries. If the user wishes to stop keyboard entry and start afresh, the program can be stopped by pressing the letter "C" while holding down the control key. The "CLS" command can be used to clear the screen.

Output File

WETSORT produces a single ASCII output file. In this example, the name of the output file is WETEXMPL.OUT, which was prompted-for in the DOS window during execution. The output file is divided into two parts. The first part is an echo of run control input, followed by a table listing the results in chronological order. The second part is repeat of the echo of run control input, followed by a table listing the results in descending order of annual wetland elevation. The example problem output file is listed in Appendix-D.

To allow the output file to be printed in large type in the appendix, the file was split into two files, WETEXMPL1.OUT and WETEXMPL2.OUT, and the top-most titles and the page numbers on the printouts were generated by Microsoft notepad, rather than WETSORT.

For the first part, shown in WETEXMPL1.OUT, the input control information consists of the output filename, the stream name, the gage location, the starting month and day of the growing season, the ending month and day of the growing season, and the duration in days. The table in chronological order lists, from left to right, a row number, the stage, the elevation (stage plus gage zero), and the starting and ending dates of the instance of duration that results in the highest wetland elevation for each year in the analysis period. It would be difficult to scan this file and spot a median wetland elevation.

For the second part, shown in WETEXMPL2.OUT, the input control information and the results are the same as for the first part, except the results in the table are sorted in descending order of wetland elevation. The ordered elevations make it easy to spot the median value, which is adopted as the wetland elevation of the analysis period. If the number of years in the analysis period is odd, then the central sorted wetland elevation is the median elevation. For example, if an analysis period consisted of 19 years, then the median elevation would be the 10-ranked elevation in the sorted table.

If the number of years in the analysis period is even, then the median is the mean of the central pair of sorted elevations. In the example problem, the analysis period is 20 years, so the median wetland elevation is the mean of the central pair of sorted elevations--26.60 and 26.50--corresponding to the 10th and 11th sorted years. Therefore, the wetland elevation for the example problem is 26.55, and **this is the "ANSWER" of the WETSORT analysis.**

Plots of Data

A plot of the example problem stage data from 1971 through 1990 inclusive is shown in Appendix-B, with the stages plotted in a solid blue line. The stages range from roughly 6 feet to 35 feet, and tend to be highest in winter and spring. Although the patterns are similar from year to year, the detail is overwhelming. It would be very difficult for a person to scan this plot by eye and estimate a wetland elevation for the analysis period.

A plot of stage data for the year 1971 is shown in Appendix-E, with stages plotted in a thick red line. The winter and spring stages are the highest. The summer and fall stages are the lowest, but they are also the most frequently fluctuating. The plot has been marked-up by hand to show the 20MAR to 10NOV growing season and the instance of duration that sets the wetland elevation for 1971. As it happens, the wetland elevation is set by the very first possible instance of 15-day duration in the growing season--20MAR to 3APR. It is the lowest elevation--17.7 feet--within the duration that sets the hydrologic elevation for that instance of duration, and for the overall growing season and calendar year.

REFERENCES

US Army Corps of Engineers, Hydrologic Engineering Center, *CPD-79 HEC-DssVue, HEC Data Storage System Visual Utility Engine, Users Manual*, Version 1.2, May, 2005 (Revised Jan, 2006).

US Army Corps of Engineers, Vicksburg District, *WETSORT*, unpublished FORTRAN 77 computer program, circa 1995.

US Department of Agriculture, National Resources Conservation Service, *Part 650 Engineering Field Handbook, Chapter 19, Hydrology Tools for Wetland Determination*, August, 1997.

APPENDICES

APPENDIX - A
NRCS DOCUMENTATION
OF METHOD

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Part 650
Engineering Field Handbook

Chapter 19 Hydrology Tools for Wetland Determination

Issued August 1997

Preface

This chapter of the Engineering Field Handbook is an outgrowth of a meeting of hydraulic and water management engineers in Wilmington, Delaware, in October 1991. The participants developed a list of hydrology tools that help delineate wetlands. Various task groups were formed for each tool. Send comments to the Natural Resources Conservation Service (NRCS), Conservation Engineering Division, Washington, DC, or the Wetland Sciences Institute, Beltsville, Maryland.

The membership in the task group is as follows:

Stream and Lake Gage	**Bill Merkel,** NRCS, Beltsville, MD
Runoff Volumes	**Bob Kluth**, NRCS, Lincoln, NE (retired) **Rodney White,** NRCS, Fort Worth, TX (retired) **Helen Moody,** NRCS, Beltsville, MD **Don Woodward**, NRCS, Washington, DC
Remote Sensing	**R.H. Griffin,** NRCS, Fort Worth, TX **Bill Merkel**, NRCS, Beltsville, MD **Rodney White**, NRCS, Fort Worth, TX (retired)
DRAINMOD	**Virgil Backlund**, NRCS, Davis, CA **Sal Palalay**, NRCS, Chester, PA (retired) **Jeff Healy**, NRCS, Indianapolis, IN (retired) **Frank Geter**, NRCS, Fort Collins, CO **Ron Marlow,** NRCS, Washington, DC
Scope and Effect Equations	**Virgil Backlund**, NRCS, Davis, CA **Frank Geter**, NRCS, Fort Collins, CO **Sal Palalay**, NRCS, Chester, PA (retired) **Jesse Wilson**, NRCS, Gainesville, FL **Rodney White**, NRCS, Fort Worth, TX (retired)
Drainage Guides	**Don Woodward**, NRCS, Washington, DC
Observation Wells	**Don Woodward**, NRCS, Washington, DC **Andrew Warne,** Corps of Engineers, Vicksburg, MS

Chapter 19 Hydrology Tools for Wetland Determination

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Chapter 19 Hydrology Tools for Wetland Determination

650.1900 Introduction

This chapter of the Engineering Field Handbook presents seven tools or procedures to use in the evaluating the hydrology of potential wetlands. Each tool is used in one or more states to assist in the determination of wetlands. These tools are analytical techniques that can be used to supplement the documentation of wetland hydrology determination.

The use of each tool depends on local conditions. The technical discipline leaders in each state office should determine the applicability of the individual tool(s) in their area. The selection of the appropriate tool(s) should be coordinated with the Environmental Protection Agency, Corps of Engineers, and Fish and Wildlife Service. Each procedure or tool is described in a separate section of this chapter.

The criteria for duration and frequency of inundation and saturation are in Section 527.4 of the National Food Security Act Manual (NFSAM). Different durations were used with the various procedures to indicate that the procedure is independent of the criteria.

The seven tools are:

- Stream gage data to establish the hydrology of over- or out-of-bank flooding.
- Water budget analysis to estimate daily runoff values, which can be used to determine the water balance of any wetland. A curve of drainage area versus depressional surface area to determine the frequency and duration of inundation of playas.
- Aerial photographic analysis to establish the frequency of occurrence and duration of inundation.
- DRAINMOD computer program to establish the degree of saturation of a wetland under a wide range of drained and nondrained conditions.
- Scope and effect equations to evaluate the effects of drainage measures on wetlands.
- Drainage guides, which provide useful information for evaluating drainage systems.
- Observation well data to establish the saturated conditions of a wetland.

650.1901 Use of stream and lake gages

(a) Applicable situations for use

Stream and lake gage data can be used to document the timing duration and frequency of inundation of the area adjacent to streams and lakes. Daily flow or stage data are used to determine the duration and frequency of overbank inundation. For a riverine situation, duration and frequency information at stream gage locations may be extended upstream or downstream using water surface profile information. Procedures for gathering stream gage data and computing water surface profiles are found in standard references.

Even if a site near a stream gage does not have sufficient topographic or stream gage data, some knowledge of the site can be obtained from analyses of the stream gage.

(b) Data required

The following data are required:

- Daily flow values or lake levels for a minimum of 10 years of data.
- Cross section information, and relationship of discharge versus stage if discharges are used.
- Topographic information for area of concern.
- Water surface profile information (if point of concern is not at the gage site).

(c) Sources of data

Various Federal, State, and county agencies have placed gages on many streams and lakes. Stream and lake gage data are available from the Corps of Engineers (COE), Tennessee Valley Authority (TVA), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), Bureau of Reclamation (BOR), various highway departments, and state or local public works agencies.

Various types of gage data are published. They include mean daily discharge, mean daily stage, peak stage and discharge for flood events, and mean daily lake level.

The primary source of data is the USGS Water Resources Data publication for each state.

(d) Limitations

(1) Knowledge and experience required

General knowledge of water surface profile computations and stream hydraulics and statistical techniques is required.

(2) Climatic regions of applicability

This procedure is applicable to all climate regions.

(3) Factors affecting the accuracy of results

The concept in this procedure is that the hydrograph can indicate what discharge or stage is exceeded for a particular duration, frequency, or both. At least 10 years of data are needed to apply this procedure. The accuracy of the procedure increases as the length of record increases.

If discharges are used, a relationship of stage versus discharge is needed to convert discharge into stage. The accuracy is a function of the cross section information. The stage is most accurately determined at the gage site. To accurately determine inundated areas using this information along the stream, the water surface profiles and topographic maps must be accurate. Even at the gage site, some topographic survey information may be needed to determine the limits of inundation if the topographic map is insufficient. The accuracy is a function of the contour interval of the map. Stream gage data may be extended upstream or downstream up to 1,000 feet without the use of a water surface profile.

Stream gage data may be used in the following situations:

1. A stream overflows and stays out of bank for the time required to meet wetland hydrology criteria.
2. A stream overflows and returns within banks in a time period less than the wetland hydrology criteria duration. The out-of-bank area must then be considered to confirm if over-bank-flow time plus time remaining ponded or saturated meets the wetland hydrology criteria. A simple water budget for the area may determine if ponding meets the ponding wetland criteria. This type of analysis is outside the scope of this chapter.
3. Areas next to a lake that may be subject to inundation because of periodic fluctuation in water level.
4. The water level in the lake may return to a normal level in less time than that required to meet the wetland hydrology criteria. The lake shore area must then be considered to confirm if the time flooded by the lake plus the time remaining ponded, saturated, or flooded meets the wetland hydrology criteria.

This section discusses situations 1 and 3. Situations 2 and 4 involve combining the methodology in situations 1 or 3 with analysis from other technical documents. Situations 2 and 4 involve analysis of the soil moisture in the soil profile using a standard water budget technique.

(e) Methodology

Methodology is a 9-step process.

Step 1. Determine growing season and duration as defined in Part 527.4 of the National Food Security Act Manual. The WETS table can be used to determine the growing season.

Step 2. Obtain available data or develop data relating to stream hydrology and hydraulics. This includes gage records, both upstream and downstream (if possible), of the site being evaluated. If the gage records are daily discharges, data relating discharge to stage must be obtained. See National Engineering Handbook, Section 4 (NEH-4), Chapter 14, Stage-Discharge Relationships. Other useful data available on many streams include water surface profiles. Water surface profiles are important where only one stream gage is located on the stream or where the potential wetland is not close to the gaging station.

Step 3. Develop a water surface profile, which is a plot of water surface elevation versus distance along a stream. The water surface elevation can represent a specific discharge or a flow frequency, such as a 2-year or 100-year discharge. A water surface profile is developed using computer programs that use cross section data, roughness data, distance along a stream, and bridge and culvert information. WSP2 and HEC2 are typical water surface computer programs used by NRCS and COE respectively.

Step 4. Use as many continuous years of gage records as can be obtained. The record should be representative of current conditions. For example, if a major dam has been installed and flow conditions have changed or channel excavation has occurred that would influence gage readings, then the gage records may be invalid and should not be used.

Step 5. Determine the highest stage of each year that is exceeded for the duration set by NFSAM or relevant criteria. Consider only gage records during the growing season. For example, if the inundation criterion is 10 days, record the lowest stage occurring within 10 days of high flow. Next, move the 10-day period forward 1 day and record the lowest stage occurring during those 10 days of high flow. It is assumed that all flows larger than the smallest flow within the criteria duration will be out of bank. Repeat this process for the entire growing season. The highest of these recorded stages is the value to use for that year. This search could be done on the larger flood events that would be expected to produce the highest 10-day stages and not for every 10-day interval of the growing season.

Repeat this process for as many years of gage data as daily records are available. If the record is broken, then determine if the discontinuous record is really representative of the site's hydrology.

Example 19–1 illustrates the determination of the elevation exceeded for 10 consecutive days on the Smith River at Brooking, Oregon, for 1989. The growing season is from March 1 to October 31. Figure 19–1 is a plot of mean daily elevation for March and April 1989, which represents the part of the growing season with the highest overall stage levels.

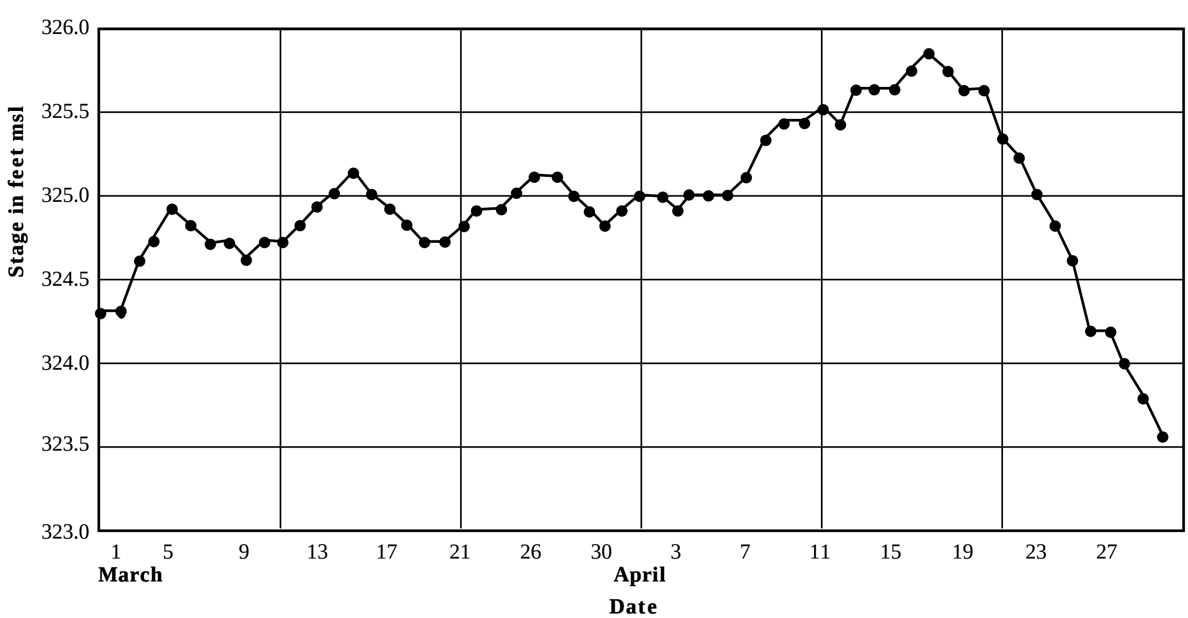
Example 19–1 Determination of elevation exceeded for 10 consecutive days

March 1–10, the lowest elevation = 324.3 feet
March 2–11, the lowest elevation = 324.3 feet.

Elevations exceed 325 in April, so these days should be checked.
April 7–16, the lowest elevation = 325.1 feet.
April 8–17, the lowest elevation = 325.3 feet.

Thus the lowest elevation that was exceeded for 10 consecutive days during 1989 was 324.3 feet.

Figure 19–1 Mean daily elevation for March and April 1989 for Smith River at Brookings, Oregon



Step 6. Tabulate the stage readings determined for each year of record for the gage in descending order (highest elevation first). The median value is the value where half of the stage readings are higher and half are lower. If an odd number of years of record is used, the middle event is the median elevation. If an even number of years of record is used, then compute the average elevation between the two middle years as the median. Example 19–2 shows the selection of the median.

Step 7. Repeat steps (4) through (6) for the second gage, if available.

Step 8. If there are two gages and if water surface profiles are not available, use the following procedure to determine median elevation. Measure the distance between the two gages along the stream and the distance from the site to the nearest of the two gages. Assume a straight line water surface between the gages and interpolate the elevation at the site based on the proportion of the distance to the gage and the distance between the two gages.

Using the data in table 19–1, the elevation at the site would be:

$$140 - [(5/20) \times 40] = 130 \text{ feet.}$$

If water surface profiles are available, interpolate the elevation at the site based on relationships of stage and discharge (and possibly frequency) at the gage locations and at the site.

Step 9. To relate the water level with the land surface, establish elevations at the site in question by a topographic survey or contour map.

Example 19–2 Selection of median stage reading

11 years of data are available and ordered from highest to lowest.

335 329 326 325.3 324 323.5 320 319 317 314 308

The median is **323.5** because 5 values are higher and 5 are lower.

10 years of data are available and ordered from highest to lowest.

335 331 329 328 325 323 322 321 320 315

The median would be **324** because it is the average of the 5th and 6th value.

Table 19–1 Example data to figure elevation

Location	Distance (miles)	15-day median elevation
Downstream gage	0	100
Site	15	?
Upstream gage	20	140

(f) Sample documentation

An area on the banks of the Tar River near Rocky Mount, North Carolina, is to be evaluated. It is assumed that the area must be inundated for 15 days during the growing season of March 1 to October 31 to have wetland hydrology present.

A stream gage is located on the Tar River at North Carolina Highway 97 in Rocky Mount, North Carolina. The USGS Water Resources Data for North Carolina include records from August 1976 to the present time. Average daily discharge data are published along with peak discharges and associated stages.

The first step is to determine the 15-day duration elevation for each year of record. Normally, the complete record is used, but in this example only 6 years are shown (table 19–2). Data for 6 years (1986 to 1991) are duplicated in the following pages with the 15-day duration discharge marked.

Example 19–3 shows records for Pamlico River Basin. The selection of the lowest flow during the high flow period is shown on pages 19–7 through 19–12.

These discharges are then ranked and the median calculated. The values ranked are 2,529, 1,300, 1,240, 679, 513, and 444. Because the number of years is even, the average of the third and fourth values is calculated. The median is 960 cubic feet per second. Because of the large difference between these values, a better estimate would result if more years were analyzed.

The next steps are to determine the stage and elevation that apply to the discharge of 960 cubic feet per second. From the publications of USGS Water Resources Data, the stage versus discharge for peak discharges is plotted and a smooth curve drawn through the points (figure 19–2). The discharge-stage curves can also be obtained from the agency responsible for the gage.

The stage associated with 960 cubic feet per second is 6.1 feet. This stage is then added to the gage datum of 53.88 feet to get an elevation of 60 feet. This elevation is then compared to the elevation of the land where the wetland determination is to be made. Any land below the elevation 60 on the flood plain would be inundated for at least 15 days by out-of-bank flooding during the growing season in 50 percent of the years, thus meeting the wetland criterion used.

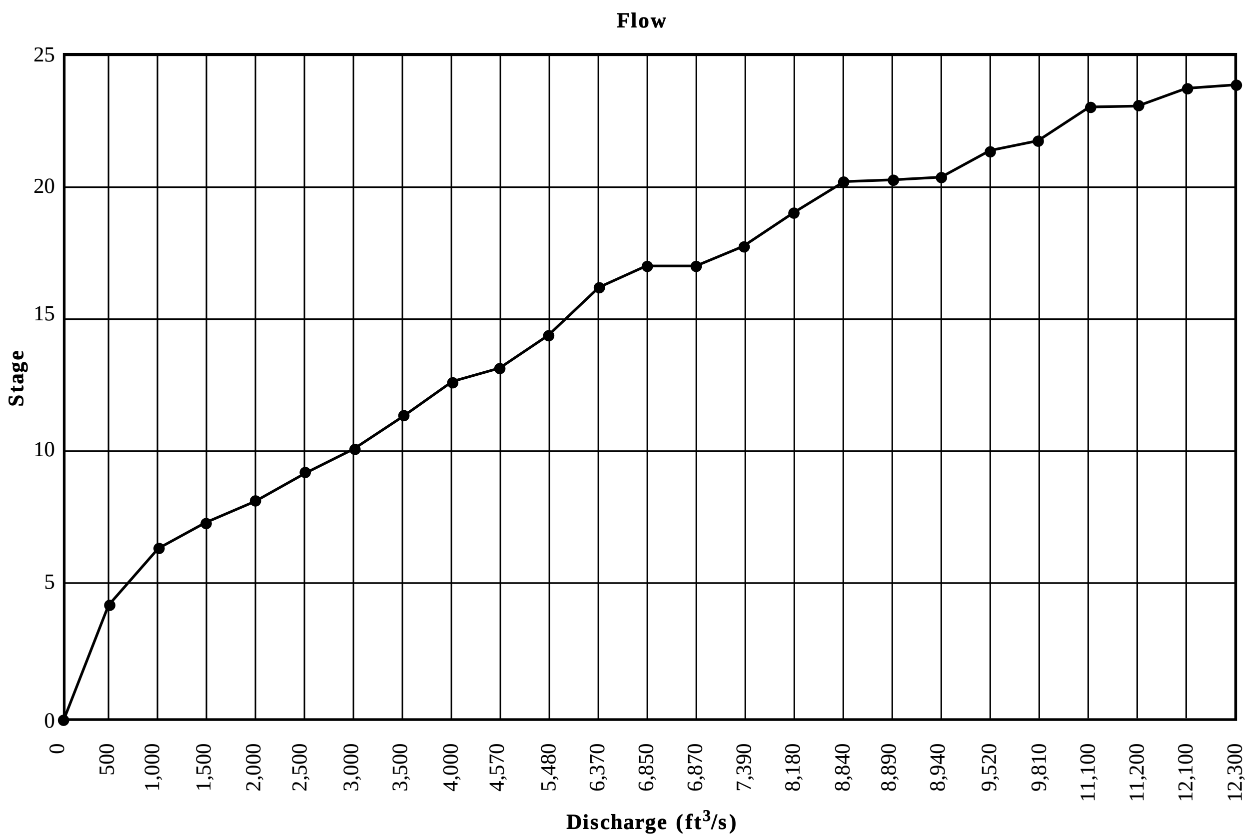
It should be noted that this elevation applies only in the immediate vicinity of the stream gage. If the area in question extends either far downstream or upstream of the road, water surface profiles would be required to determine the elevation.

In this procedure we assume that there are no levees between the stream and potential wetland.

Table 19–2 15-day duration elevation, 1986–1991

Year	Month-day	Discharge	Ranked
1986	3–25	444	2529
1987	4–15	1,300	1300
1988	4–27	513	1240
1989	5–11	2,529	679
1990	4–12	1,240	513
1991	3–12	679	444

Figure 19–2 Stage versus discharge plot for Tar River at Rocky Mount, North Carolina



Example 19–3 Water discharge records for Pamlico River Basin

Pamlico River Basin—02082585 Tar River at NC 97 at Rocky Mount, NC

Location—Lat 35°57'15", long 77°47'15", Edgecombe County, Hydrologic Unit 03020101, on left bank 20 feet downstream from bridge on NC 97, 0.5 mile upstream from Cowlick Branch, and 1.0 mile north-northeast of Rocky Mount.

Drainage area—925 square miles.

Water-Discharge Records

Period of Record—August 1976 to current year.

Revised Records—WDR NC-81-1: Drainage area.

Gage—Water-stage recorder. Datum of gage is 53.88 ft. above National Geodetic Vertical Datum of 1929.

Remarks—No estimated daily discharges. Records good except those below 10 ft^3/s, which are fair. Some regulation at low flow by mill above station. The city of Rocky Mount diverted an average of 17.8 ft^3/s for municipal water supply, most of which was returned as sewage below station.

Cooperation—Chemical and biological data shown in last table were provided by the North Carolina Department of Natural Resources and Community Development.

Average Discharge—10 years, 906 ft^3/s, 13.30 in/yr.

Extremes for Period of Record—Maximum discharge, 12,300 ft^3/s May 1, 1978, gage height, 23.66 ft; minimum, 6.1 ft^3/s Oct. 2, 1983, gage height, 2.84 ft.

Extremes for Current Year—Maximum discharge, 8,180 ft^3/s Nov. 26, gage height, 19.06 ft; minimum, 8.3 ft^3/s July 3, gage height, 2.96 ft.

Discharge, in cubic feet per second, water year October 1985 to September 1986 (mean values)

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	75	138	2670	403	655	897	494	249	264	101	46	696
2	242	140	3980	406	597	98	473	223	194	109	51	490
3	413	139	4430	444	542	710	459	211	164	20	210	368
4	234	419	2870	458	529	189	441	197	149	16	123	252
5	78	876	1280	472	512	102	440	158	139	26	77	202
6	116	2400	968	439	484	145	441	127	134	43	66	246
7	129	3200	834	378	495	152	502	138	135	54	226	197
8	139	2140	746	358	500	153	617	97	153	58	124	239
9	134	721	658	339	527	154	681	83	142	60	88	197
10	127	456	612	319	518	155	579	83	134	62	98	118
11	162	361	565	313	550	245	587	82	129	64	182	155
12	65	322	547	347	582	360	357	82	126	64	423	213
13	110	738	738	337	632	407	421	82	123	64	363	188
14	102	34	930	332	665	717	400	102	118	30	491	134
15	104	77	1650	313	597	1430	391	106	128	51	1060	210
16	104	119	1310	304	549	2880	330	106	106	50	823	58
17	104	148	907	298	532	3510	185	105	108	55	449	114
18	106	197	742	296	520	2440	240	112	106	53	313	109
19	109	136	630	344	1590	1160	302	113	105	54	715	106
20	111	247	571	467	932	1070	327	125	104	54	1230	108
21	141	369	528	553	1670	1420	344	175	106	53	1150	107
22	143	1670	499	512	1140	1580	338	840	93	54	2440	104
23	146	3990	474	423	675	1330	356	1410	57	49	3250	102
24	132	5250	481	374	576	883	341	790	61	47	2950	99
25	143	6640	482	361	549	444	323	441	83	46	899	96
26	159	7970	470	612	549	657	312	319	88	45	519	95
27	154	6170	425	1100	569	634	297	260	90	53	299	120
28	143	1300	393	1750	584	592	276	315	92	58	1260	73
29	133	868	395	1420	—	560	269	300	260	53	1260	173
30	128	1370	399	960	—	529	257	274	140	52	2520	55
31	128	—	391	757	—	505	—	299	—	48	1940	—
Total	4312	48605	32575	16189	18820	26977	11780	8004	3841	1676	25635	5454
Mean	139	1620	1051	522	672	870	393	258	128	54.1	827	182
Max	413	7970	4430	1750	1670	3510	681	1410	264	109	3250	696
Min	65	34	391	296	484	102	185	82	57	16	46	55
CFSM	.15	1.75	1.14	.56	.73	.94	.42	.28	.14	.06	.89	.20
In	.17	2.0	1.3	.65	.76	1.1	.47	.32	.15	.07	1.0	.22

Cal YR 1985 Total 275431 Mean 755 Max 7970 Min 34 CFSM .82 In 11
WRT YR 1986 Total 203870 Mean 559 Max 7970 Min 16 CFSM .60 In 8.2

Example 19–3 Water discharge records for Pamlico River Basin—Continued

Pamlico River Basin—02082585 Tar River at NC 97 at Rocky Mount, NC

Location—Lat 35°57'15", long 77°47'15", Edgecombe County, Hydrologic Unit 03020101, on left bank 20 feet downstream from bridge on NC 97, 0.5 mile upstream from Cowlick Branch, and 1.0 mile north-northeast of Rocky Mount.

Drainage area—925 square miles.

Water-Discharge Records

Period of Record—August 1976 to current year.

Revised Records—WDR NC-81-1: Drainage area.

Gage—Water-stage recorder. Datum of gage is 53.88 ft above National Geodetic Vertical Datum of 1929.

Remarks—No estimated daily discharges. Records good. Some regulation at low flow by mill above station. The city of Rocky Mount diverted an average of 17.8 ft^3/s for municipal water supply, most of which was returned as treated effluent below station.

Cooperation—Chemical and biological data shown in last table were provided by the North Carolina Department of Natural Resources and Community Development.

Average Discharge—11 years, 928 ft^3/s, 13.62 in/yr.

Extremes for Period of Record—Maximum discharge, 12,300 ft^3/s May 1, 1978, gage height, 23.66 ft; minimum, 6.1 ft^3/s Oct. 2, 1983, Oct 10, 1986; minimum gage height, 2.84 ft Oct 2, 1983.

Extremes for Current Year—Maximum discharge, 12,100 ft^3/s Apr 18, gage height, 23.55 ft; minimum, 6.1 ft^3/s Oct 10, minimum gage height, 2.86 ft Dec 4.

Discharge, in cubic feet per second, water year October 1986 to September 1987 (mean values)

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	56	74	161	713	1330	6660	1730	1080	313	228	100	69
2	79	80	122	1800	1660	8390	1670	951	247	197	102	45
3	139	134	139	2910	1480	8830	1310	996	296	144	101	46
4	28	11	27	3751	1450	8220	1150	976	379	116	100	46
5	87	145	283	2250	1370	8660	1170	935	395	57	94	268
6	81	34	437	1091	1150	8170	1230	857	456	287	91	115
7	81	86	355	791	959	3370	1110	728	345	346	102	77
8	85	158	283	634	846	1420	964	653	316	269	97	78
9	274	43	246	546	725	1290	569	613	260	210	98	63
10	63	156	260	518	673	2890	777	555	213	172	107	72
11	12	26	216	519	601	4300	725	497	190	164	89	80
12	17	46	310	484	562	5540	738	469	177	165	84	173
13	57	83	710	450	528	5750	844	448	165	144	84	331
14	94	85	959	420	524	4190	835	412	159	127	83	608
15	112	120	632	390	505	1820	1300	395	247	117	94	777
16	16	115	459	376	518	1410	6550	319	161	113	87	503
17	142	106	337	375	783	1270	10100	449	242	110	79	347
18	21	102	317	744	1140	1190	11800	428	415	116	75	211
19	80	109	294	4160	1490	1240	11200	356	948	113	75	155
20	79	111	275	6920	1700	1690	10700	605	635	109	72	664
21	78	111	255	7470	1710	1620	9490	762	414	105	70	514
22	76	110	248	8070	1940	1580	5620	902	322	103	71	418
23	73	111	231	9110	4110	1240	2080	730	325	103	66	273
24	72	193	653	9510	5160	1030	1560	553	350	101	57	226
25	78	25	1040	8850	5880	2000	2930	470	491	107	55	170
26	144	144	1890	6730	5900	156	4730	367	547	107	53	142
27	28	47	3100	3000	5890	466	4560	394	353	102	48	123
28	69	134	1950	1860	5770	1140	2730	405	428	102	44	105
29	84	111	855	1430	—	2270	1970	436	292	103	44	230
30	137	46	589	1250	—	3320	1260	320	270	99	49	88
31	14	—	459	1160	—	2400	—	109	—	98	99.2	—
Total	2456	2855	18092	88280	56354	103222	103402	18380	10261	4434	2470.2	7020
Mean	79.2	95.2	584	2848	2013	3330	3447	593	342	143	79.7	234
Max	274	193	3100	9510	5900	8830	11800	1080	948	346	407	777
Min	12	11	24	675	505	156	725	319	159	57	44	46
CFSM	.09	.10	.63	3.08	2.18	3.60	3.73	.64	.37	.15	.09	.25
Inch	.10	.11	.73	3.55	2.27	4.15	4.16	.74	.41	.18	.10	.28

Cal Yr 1986	Total 141779.0	Mean 388	Max 3510	Min 11	CFSM .42	In. 5.70
WTR Yr 1987	Total 417226.2	Mean 1143	Max 11800	Min 11	CFSM 1.24	In. 16.8

Example 19–3 Water discharge records for Pamlico River Basin—Continued

Pamlico River Basin—02082585 Tar River at NC 97 at Rocky Mount, NC

Location—Lat 35°57'15", long 77°47'15", Edgecombe County, Hydrologic Unit 03020101, on left bank 20 feet downstream from bridge on NC 97, 0.5 mile upstream from Cowlick Branch, and 1.0 mile north-northeast of Rocky Mount.
Drainage area—925 square miles.
Period of Record—August 1976 to current year.
Revised Records—WDR NC-81-1: Drainage area.
Gage—Water-stage recorder. Datum of gage is 53.88 ft above National Geodetic Vertical Datum of 1929.
Remarks—Records good except for estimated daily discharges, which are fair. Some regulation at low flow by mill above station. The city of Rocky Mount diverted an average of 19.9 ft^3/s for municipal water supply, most of which was returned as sewage below station. Minimum discharge for period of record and current water year also occurred on Sep. 24; result of temporary regulation.

Discharge, cubic feet per second, water year October 1987 to September 1988 (daily mean values)

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	21	70	499	1120*	587	365	475	482	174	140	67	84
2	82	97	474	*800	566	301	350	319	144	126	111	49
3	104	97	378	*850	722	379	404	408	13	126	39	126
4	107	94	292	*1300	916	407	457	278	207	242	111	98
5	102	140	243	*1880	1229	43	416	600	225	168	118	113
6	103	115	211	*2150	2160	510	396	751	230	82	79	87
7	123	100	170	*1680	1970	488	415	916	209	59	80	86
8	110	96	78	*1180	1210	472	460	816	162	65	93	73
9	109	81	69	*780	924	470	365	668	175	97	130	77
10	119	75	101	*750	815	460	482	530	179	73	83	85
11	126	78	133	*692	876	546	444	474	142	169	26	114
12	114	75	175	*600	1790	710	418	423	158	143	121	101
13	111	121	206	*570	2210	736	523	239	218	127	100	76
14	109	140	208	*560	2430	623	765	239	167	118	54	72
15	105	78	308	526	1840	560	872	276	124	121	60	90
16	108	69	350	377	1310	504	792	291	106	122	133	86
17	111	73	477	448	4080	458	668	315	102	120	121	85
18	111	63	564	695	952	415	520	362	248	103	62	71
19	104	98	458	956	891	484	669	274	250	54	75	57
20	102	96	364	1490	702	518	1190	570	190	107	88	59
21	101	108	342	1910	814	532	1840	486	281	104	99	64
22	102	81	342	2270	684	541	1640	402	358	123	116	162
23	104	79	383	1770	674	505	1071	268	372	124	131	101
24	108	132	415	1160	587	448	819	371	303	111	90	33
25	180	74	388	900	549	420	636	255	241	110	44	149
26	224	93	356	898	520	411	572	356	176	108	45	100
27	115	106	358	1000	510	503	513	243	194	120	47	233
28	107	156	638	1120	405	626	370	245	162	242	95	187
29	85	292	1030	948	454	655	560	243	141	126	64	137
30	20	465	1850	733	—	578	511	243	158	125	121	11
31	32	—	1720	567	—	509	—	240	—	93	64	—
Mean	105	155	438	1054	1047	505	654	406	200	120	86.1	98.9
Max	224	465	1850	2270	2430	736	1840	916	372	242	133	233
Min	20	63	69	377	405	301	350	239	102	54	26	33
Inch	.13	.01	.55	1.31	1.22	.63	.79	.51	.24	.15	.11	.12

*Estimated

Statistics of monthly flow data for period of record, by water year (WY)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	220.2	561.4	819.0	1568	1624	1994	1646	896.2	682.3	384.3	336.1	218.5
Max	566.8	1905	1720	3230	3280	3577	3447	2361	2238	1316	826.9	805.1
(WY)	1980	1980	1984	1978	1983	1983	1987	1978	1982	1984	1986	1979
Min	70.4	74.5	141.9	254.0	546.3	476.9	359.3	258.2	128.0	54.1	79.7	84.3
(WY)	1981	1981	1981	1981	1977	1981	1981	1986	1986	1986	1987	1980

Summary statistics	1988 water year		Period of record	
Average flow	400.4		883.9	
Highest annual mean			1500	1984
Lowest annual mean			261.9	1981
Highest daily mean	2430	Feb 14	12100	May 1, 1978
Lowest daily mean	20	Oct 30	6.6	Oct 3, 1983
Instantaneous peak flow	2510	Feb 14	12300	May 1, 1978

Summary statistics	1988 water year		Period of record	
Instantaneous peak stage	8.94	Feb 14	23.66	May 1, 1978
Instantaneous low flow	5.7	Sep 23	5.7	Sep 23, 1988
Annual runoff (inches)	5.88		13.0	
10 percentile	890		2190	
50 percentile	238		406	
98 percentile	65		70	

Example 19–3 Water discharge records for Pamlico River Basin—Continued

Pamlico River Basin—02082585 Tar River at NC 97 at Rocky Mount, NC

Location—Lat 35°57'15", long 77°47'15", Edgecombe County, Hydrologic Unit 03020101, on left bank 20 feet downstream from bridge on NC 97, 0.5 mile upstream from Cowlick Branch, and 1.0 mile north-northeast of Rocky Mount.
Drainage area—925 square miles.
Period of Record—August 1976 to current year.
Revised Records—WDR NC-81-1: Drainage area.
Gage—Water-stage recorder. Datum of gage is 53.88 ft above National Geodetic Vertical Datum of 1929.
Remarks—Records good except for estimated daily discharges, which are fair. Some regulation at low flow caused by mill above station. The city of Rocky Mount diverted an average of 19.4 ft^3/s for municipal water supply, most of which was returned as treated effluent below station. Minimum discharge for period of record and current water year, result of temporary regulation.

Discharge, cubic feet per second, water year October 1988 to September 1989 (mean daily values)

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	143	631	1160	350	303	5960	2310	7310	60	1220	509	401
2	103	1440	730	483	302	6680	2890	9200	198	804	813	347
3	20	2900	563	772	306	3750	1940	8920	314	560	1290	301
4	331	2670	420	943	284	7260	1370	7950	338	509	1040	278
5	126	1240	364	727	340	5780	1300	6750	599	473	748	270
6	99	821	305	597	410	5150	2820	5590	1040	491	510	137
7	81	639	272	520	560	6200	4030	4590	1350	524	420	183
8	365	571	248	476	674	4850	6110	4860	1440	643	419	185
9	240	451	249	462	666	5310	6510	4100	1420	893	369	183
10	181	392	262	493	700	5630	6050	2948	1250	653	342	212
11	151	316	259	515	638	4560	5740	2529	1030	489	303	145
12	143	274	264	667	546	3060	3930	2298	775	389	312	155
13	101	249	272	754	472	2290	2090	1780	873	362	353	*150
14	50	226	1100	872	436	2030	1620	1360	1030	402	413	*160
15	50	210	624	1070	406	2510	1790	1100	1200	779	416	*200
16	55	200	119	972	370	2720	2470	1480	1100	1160	751	*250
17	67	233	69	809	411	2360	3400	1560	1770	1610	900	*220
18	66	238	128	680	589	2970	2700	1400	2750	3310	1430	*190
19	126	247	120	601	779	2320	1750	1180	2380	4250	2990	*180
20	89	288	121	546	1040	1910	1450	909	1650	4540	4250	*170
21	136	263	115	488	2010	1740	1130	794	2360	2160	2600	*180
22	150	256	111	447	4920	1400	990	832	3390	872	1020	*170
23	189	245	113	402	6870	2050	937	501	3320	674	711	*180
24	201	235	149	387	7760	4950	864	725	2320	504	503	*170
25	28	210	204	366	7760	6680	770	697	1900	477	463	*160
26	240	204	237	359	8270	7500	1830	560	2000	415	1500	*200
27	188	207	243	342	7080	7170	2590	570	1320	374	2160	*300
28	151	243	259	331	5180	7070	3300	507	904	329	1090	*240
29	130	780	224	329	—	4610	2610	459	720	335	694	*220
30	120	1170	225	318	—	1790	4830	398	803	345	533	*180
31	129	—	261	302	—	1750	—	433	—	392	443	—
Mean	148	592	316	561	2146	4301	2733	2725	1699	998	977	211
Max	365	2900	1160	1070	8270	7500	6510	9200	3390	4540	4250	401
Min	20	200	69	302	284	1400	770	398	198	329	303	137
In.	.18	.71	.39	.70	2.42	5.36	3.30	3.40	1.69	1.24	1.22	.25

* Estimated

Statistics of monthly flow data for period of record, by water year (WY)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	214.7	563.8	780.3	1491	1664	2172	1452	1037	737.5	461.5	385.4	217.9
Max	566.8	1905	1720	3230	3280	4301	3447	2725	2238	1316	977.3	805.1
(WY)	1980	1980	1984	1978	1983	1989	1987	1989	1982	1984	1989	1979
Min	7034	74.5	141.9	254.0	546.3	476.9	359.3	258.2	128.0	54.1	79.7	84.3
(WY)	1981	1981	198=1	1981	1977	1981	1981	1986	1986	1986	1987	1980

Summary statistics	1989 water year		Period of record	
Average flow	1422		925.3	
Highest annual mean		1500	1984	
Lowest annual mean		261.9	1981	
Highest daily mean	9200	May 2	12100	May 1, 1978
Lowest daily mean	20	Oct	6.6	Oct 3, 1983
Instantaneous peak flow	9520	May 2	12300	May 1, 1978

Summary statistics	1989 water year		Period of record	
Instantaneous peak stage	21.23	May 2	23.66	May 1, 1978
Instantaneous low flow	5.9	Oct 6	5.7	Sep 23, 1988
Annual runoff (inches)	20.9		13.6	
10 percentile	4400		2310	
50 Percentile	579		419	
95 percentile	121		72	

Example 19–3 Water discharge records for Pamlico River Basin—Continued

Pamlico River Basin—02082585 Tar River at NC 97 at Rocky Mount, NC

Location—Lat 35°57'15", long 77°47'15", Edgecombe County, Hydrologic Unit 03020101, on left bank 20 feet downstream from bridge on NC 97, 0.5 mile upstream from Cowlick Branch, and 1.0 mile north-northeast of Rocky Mount.
Drainage area—925 square miles.
Period of Record—August 1976 to current year.
Revised Records—WDR NC-81-1: Drainage area.
Gage—Water-stage recorder. Datum of gage is 53.88 ft above National Geodetic Vertical Datum of 1929.
Remarks—Records good except for estimated daily discharges, which are fair. Some regulation at low flow caused by mill above station. The city of Rocky Mount diverted an average of 19.4 ft^3/s for municipal water supply, most of which was returned as treated effluent below station. Minimum discharge for period of record and current water year, result of temporary regulation.

Discharge, cubic feet per second, water year October 1989 to September 1990 (mean daily values)

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	*513	*388	*410	1020	1350	1100	7160	1360	3140	160	64	1130
2	1010	*400	*320	1230	1180	1070	6330	2430	1390	170	59	657
3	2190	*809	*250	1730	1070	1440	6350	2340	860	222	89	382
4	3640	*1480	*200	1440	1040	1690	5600	2250	1100	315	76	286
5	4300	*1860	*460	1120	865	1830	5770	2250	880	367	101	245
6	2990	*1270	864	1080	1330	1600	5750	2310	732	264	89	202
7	963	*896	274	1110	1550	1220	3640	2330	596	278	79	187
8	673	*608	1260	1720	1200	1070	2170	1850	485	145	73	163
9	798	*758	1980	2300	1090	985	2430	1160	464	157	172	165
10	459	*1210	3270	3130	1780	930	1750	952	414	136	2470	230
11	*395	*1990	2590	3440	2390	627	1650	1270	362	132	1700	231
12	*372	*1400	2140	2070	3530	890	1240	2510	343	127	971	235
13	*340	*966	3550	1390	370	855	1130	2160	320	123	514	01
14	*319	*722	4620	1160	2260	781	1030	1200	302	186	341	252
15	*303	*964	5400	1030	1400	751	973	963	280	318	290	280
16	*296	*869	5580	942	1240	767	978	805	270	329	246	153
17	*289	*1420	4140	905	1570	789	1450	705	263	387	283	158
18	*309	*1100	2260	869	3080	1450	1390	608	256	554	255	315
19	*851	*900	2040	827	4690	1920	1150	551	269	237	239	82
20	*2690	*780	1941	819	5100	1940	1020	447	248	373	316	289
21	*2930	*670	2770	1281	3990	1350	892	444	197	305	307	96
22	*1940	*900	1600	1620	2800	1050	822	586	256	238	252	31
23	*1170	*1200	1100	1720	1940	911	829	846	308	190	375	49
24	*783	*1600	923	1420	2140	828	840	1000	323	83	2620	77
25	*608	*2100	870	1140	2280	789	792	861	315	109	4440	88
26	*515	*2900	797	1260	1800	754	717	683	286	93	3590	135
27	*462	*1700	270	1990	1360	719	664	596	244	81	211	28
28	*433	*1050	211	3160	1170	712	608	663	172	76	1640	32
29	*409	*740	221	2820	—	2320	551	1580	206	92	972	46
30	*400	*530	162	1650	—	5680	829	2430	123	78	1290	74
31	*401	—	774	1420	—	6930	—	3250	—	74	1270	—
Mean	1079	1130	1708	1575	2109	1485	2207	1401	513	205	880	217
Max	4300	2900	5580	3440	5100	6930	7160	3250	3140	554	4440	1130
Min	289	388	162	819	865	712	551	444	123	74	59	28
In.	1.35	1.36	2.13	1.96	2.38	1.85	2.66	1075	.62	.26	1.10	.26

* Estimated

Statistics of monthly flow data for period of record, by water year (WY)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	276.4	604.2	846.6	12497	1696	2123	1805	1063	721.5	415.3	420.8	217.8
Max	1079	1905	1720	3230	3280	4301	3447	2725	2238	1316	977.3	805.1
(WY)	1990	1980	1984	1978	1983	1989	1987	1989	1982	1984	1989	1979
Min	70.1	74.5	141.9	254.0	546.3	476.9	359.3	258.2	128.0	5431	79.7	84.3
(WY)	1981	1981	1981	1981	1977	1981	1981	1986	1986	1986	1987	1980

Summary statistics	1990 water year		Period of record	
Average flow	1204		945.2	
Highest annual mean		1500	1981	
Lowest annual mean		261.9	1981	
Highest daily mean	7160	Apr 1	12100	May 1, 1978
Lowest daily mean	28	Sep 27	6.6	Oct 3, 1983
Instantaneous peak flow	7390	Apr 1	12300	May 1, 1978

Summary statistics	1990 water year		Period of record	
Instantaneous peak stage	7.74	Apr 1	23.66	May 1, 1978
Instantaneous low flow	8.6	Sep 19	5.7	Sep 23, 1988
Annual runoff (inches)	17.7		13.9	
10 percentile	2670		2350	
50 Percentile	860		437	
95 percentile	86		73	

Example 19–3 Water discharge records for Pamlico River Basin—Continued

Pamlico River Basin—02082585 Tar River at NC 97 at Rocky Mount, NC

Location—Lat 35°57'15", long 77°47'15", Edgecombe County, Hydrologic Unit 03020101, on left bank 20 feet downstream from bridge on NC 97, 0.5 mile upstream from Cowlick Branch, and 1.0 mile north-northeast of Rocky Mount.
Drainage area—925 square miles. Period of Record—August 1976 to current year. Revised Records—WDR NC-81-1: Drainage area.
Gage—Water-stage recorder. Datum of gage is 53.88 ft above National Geodetic Vertical Datum of 1929.
Remarks—No estimated daily discharges. Records good. Some regulation at low flow caused by mill above station. The city of Rocky Mount diverted an average of 24.1 ft^3/s for municipal water supply, most of which was returned as treated effluent below station. Minimum discharge for period of record and current water year, result of temporary regulation. Gage-height telemeter at station.

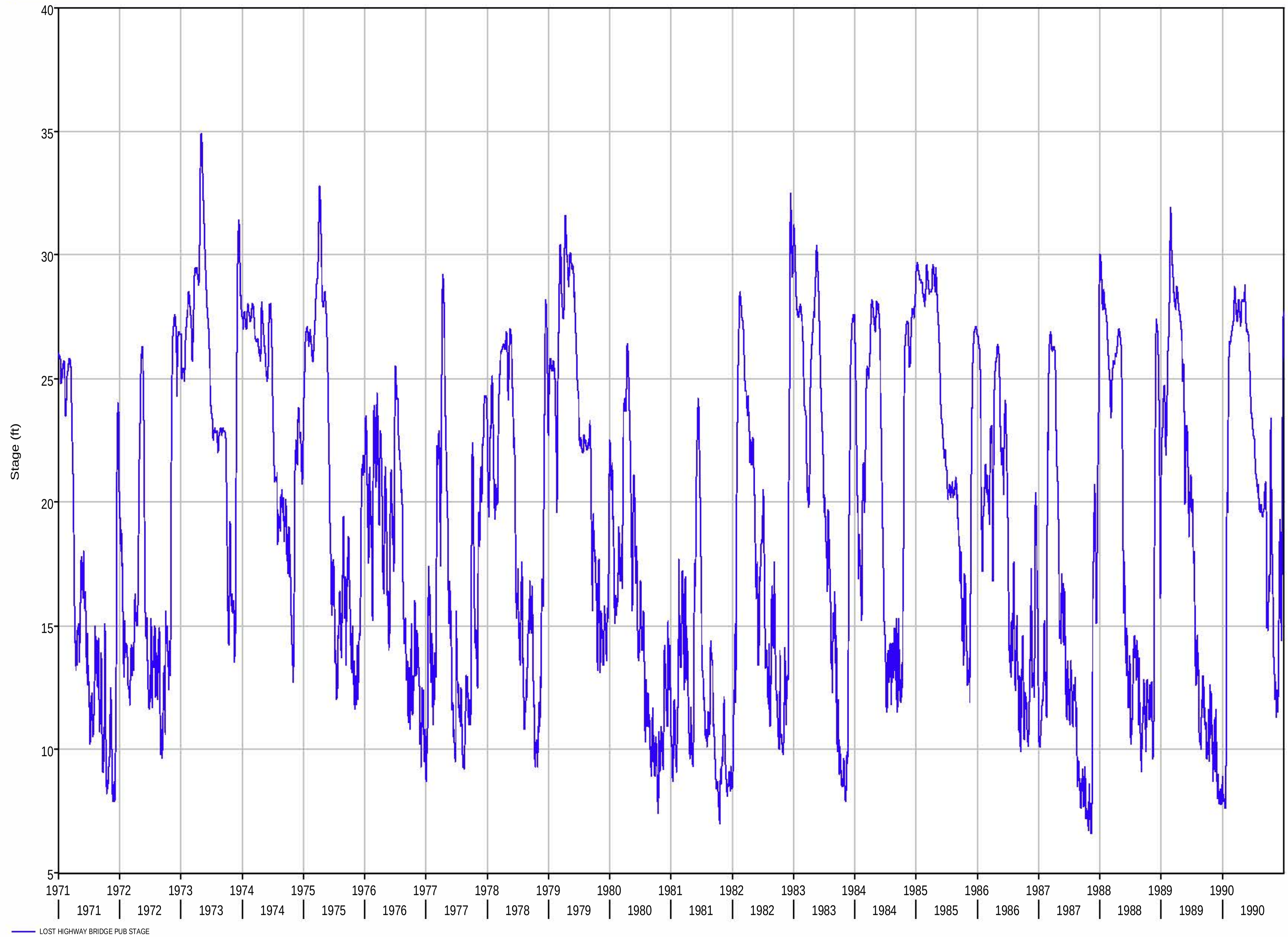
Discharge, cubic feet per second, water year October 1990 to September 1991 (mean daily values)

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	79	222	843	823	821	1990	4371	915	267	87	419	192
2	102	201	700	1410	767	667	4810	1290	175	94	413	128
3	58	191	526	1290	686	359	3838	877	212	133	226	98
4	64	177	449	4111	634	1470	1310	612	168	109	205	98
5	68	168	392	924	688	2791	957	468	301	123	175	98
6	192	161	512	805	58	3358	847	463	247	118	103	119
7	139	148	616	960	898	1930	813	342	282	113	118	210
8	119	147	632	1870	669	1200	744	369	185	105	93	164
9	117	141	601	3230	801	992	674	347	142	90	105	133
10	118	345	581	4000	762	858	670	323	128	85	162	102
11	136	308	558	3180	681	749	576	3873	105	131	165	101
12	93	338	509	2850	613	679	550	291	96	89	137	89
13	108	446	437	4200	582	679	495	286	96	101	341	106
14	107	381	375	5200	573	836	584	257	91	107	259	119
15	96	297	224	5471	496	1091	544	288	141	115	889	117
16	123	249	329	4391	585	1380	308	362	137	104	847	118
17	131	228	384	1690	472	1050	745	134	93	109	672	117
18	146	211	366	1610	477	1060	727	156	102	103	429	105
19	144	200	370	1520	489	1440	565	330	96	84	240	97
20	133	183	370	1630	527	2310	889	599	155	92	196	118
21	124	215	532	1930	612	1790	775	805	149	71	154	116
22	121	156	879	2780	654	1180	744	860	141	77	132	82
23	231	194	1220	2120	684	961	754	715	107	82	130	67
24	344	190	1140	1340	563	952	793	509	95	80	109	102
25	1510	197	842	1120	526	897	653	406	89	75	89	107
26	1490	198	652	969	515	796	511	327	99	69	8	117
27	822	198	521	886	517	129	471	274	108	77	141	111
28	610	209	601	824	562	662	477	272	101	100	135	105
29	454	416	637	784	—	689	453	340	89	305	132	104
30	313	895	687	779	—	1390	625	314	90	545	156	102
31	258	—	723	833	—	3150	—	287	—	423	184	—
Total	8550	7500	18200	32577	16983	39115	31474	14141	4209	4004	7633	3442
Mean	276	253	587	2019	607	1262	1049	456	140	129	246	115
Max	1510	865	1220	5470	521	3358	4810	1290	301	545	889	210
Min	58	141	224	779	472	359	453	134	89	69	87	67
CFSM	.30	.27	.63	2.18	.66	1.36	1.13	.49	.15	.14	.27	.12
In.	.34	.30	.73	2.52	.68	1.57	1.27	.57	.17	.16	.31	.14
Mean	276	501	829	1531	1623	2065	1476	1022	683	396	409	211
Max	1079	1905	1720	3230	3260	4301	3447	2725	2238	1316	977	805
(WY)	1990	1980	1984	1978	1983	1989	1987	1989	1982	1984	1989	1979
Min	70.4	74.5	142	254	546	477	359	258	128	54.1	79.7	84.3
(WY)	1981	1981	1981	1981	1977	1981	1981	1986	1986	1986	1987	1980

Summary statistics	1990 calendar year		1991 water year		1977-1991 water years	
Annual total	353444		217908			
Annual mean	9678		597		922	
Highest annual mean				1500	1984	
Lowest annual mean				262	1981	
Highest daily mean	7160	Apr 1	5470	Jan 15	12100	May 1, 1978
Lowest daily mean	28	Sep 27	58	Oct 3	6.6	Oct 3, 1983
Annual 7-day minimum	60	Sep 27	76	Jul 21	40	Jul 3, 1986
Instantaneous peak flow			5480	Jan 15	12300	May 1, 1978
Instantaneous peak stage			14.43	Jan 15	23.66	May 1, 1978
Instantaneous low flow			7.2	Nov 1	5.7	Sep 23, 1988
Annual runoff (CFSM)	1.05		.68		1.00	
Annual runoff (inches)	14.21		8.76		13.54	
10 percentile	2290		1250		2280	
50 Percentile	601		344		430	
95 percentile	118		98		99	

APPENDIX - B
EXAMPLE PROBLEM
PLOT OF STAGES
1971 - 1990

Nowhere River at Lost Highway Bridge



APPENDIX - C
EXAMPLE PROBLEM
WETSORT DOS WINDOW
SCREEN SHOTS

Screen Shot of DOS Window During WETSORT Execution

Command Prompt

```
U:\HUNTR\~wetsort>WETSORT
ENTER YOUR OUTPUT FILENAME :
WETEXMPL.OUT
ENTER STREAM NAME :
NOWHERE RIVER
ENTER LOCATION OF GAGE :
LOST HIGHWAY BRIDGE
ENTER STARTING YEAR :
1971
ENTER ENDING YEAR :
1990
ENTER STARTING MONTH OF GROWING SEASON :
3
ENTER STARTING DAY OF GROWING SEASON :
20
ENTER ENDING MONTH OF GROWING SEASON :
11
ENTER ENDING DAY OF GROWING SEASON :
10
ENTER NUMBER OF DAYS OF FIVE PERCENT DURATION :
15
ENTER GAGE ZERO :
0.00
ENTER YOUR DSS FILENAME :
WETEXMPL.DSS
ENTER PATHNAME (no D part) :
/NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAGE//1DAY/PUB/
   -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                      Unit:  71;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  71; Vers.    3:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1971/1DAY/PUB/
   -----DSS---ZCLOSE Unit:  71,   File: WETEXMPL.DSS
              Pointer Utilization:   .15
              Number of Records:   100
              File Size:    291.6  Kbytes
              Percent Inactive:    .0
NBVAL=         79NEVAL=        314
   -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                      Unit:  72;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  72; Vers.    3:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1972/1DAY/PUB/
   -----DSS---ZCLOSE Unit:  72,   File: WETEXMPL.DSS
              Pointer Utilization:   .15
              Number of Records:   100
              File Size:    291.6  Kbytes
              Percent Inactive:    .0
NBVAL=         80NEVAL=        315
   -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                      Unit:  73;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  73; Vers.    3:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1973/1DAY/PUB/
   -----DSS---ZCLOSE Unit:  73,   File: WETEXMPL.DSS
              Pointer Utilization:   .15
              Number of Records:   100
              File Size:    291.6  Kbytes
              Percent Inactive:    .0
NBVAL=         79NEVAL=        314
   -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                      Unit:  74;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  74; Vers.    3:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1974/1DAY/PUB/
   -----DSS---ZCLOSE Unit:  74,   File: WETEXMPL.DSS
              Pointer Utilization:   .15
              Number of Records:   100
              File Size:    291.6  Kbytes
              Percent Inactive:    .0
NBVAL=         79NEVAL=        314
   -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                      Unit:  75;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  75; Vers.    3:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1975/1DAY/PUB/
   -----DSS---ZCLOSE Unit:  75,   File: WETEXMPL.DSS
              Pointer Utilization:   .15
              Number of Records:   100
              File Size:    291.6  Kbytes
              Percent Inactive:    .0
NBVAL=         79NEVAL=        314
   -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                      Unit:  76;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  76; Vers.  367:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1976/1DAY/PUB/
```

Screen Shot of DOS Window During WETSORT Execution

Command Prompt

```
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  76;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  76; Vers.  367:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1976/1DAY/PUB/
     -----DSS---ZCLOSE Unit:  76,    File: WETEXMPL.DSS
                Pointer Utilization:    .15
                Number of Records:    100
                File Size:    291.6  Kbytes
                Percent Inactive:     .0
NBVAL=           80NEVAL=          315
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  77;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  77; Vers.    3:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1977/1DAY/PUB/
     -----DSS---ZCLOSE Unit:  77,    File: WETEXMPL.DSS
                Pointer Utilization:    .15
                Number of Records:    100
                File Size:    291.6  Kbytes
                Percent Inactive:     .0
NBVAL=           79NEVAL=          314
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  78;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  78; Vers.    6:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1978/1DAY/PUB/
     -----DSS---ZCLOSE Unit:  78,    File: WETEXMPL.DSS
                Pointer Utilization:    .15
                Number of Records:    100
                File Size:    291.6  Kbytes
                Percent Inactive:     .0
NBVAL=           79NEVAL=          314
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  79;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  79; Vers.    3:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1979/1DAY/PUB/
     -----DSS---ZCLOSE Unit:  79,    File: WETEXMPL.DSS
                Pointer Utilization:    .15
                Number of Records:    100
                File Size:    291.6  Kbytes
                Percent Inactive:     .0
NBVAL=           79NEVAL=          314
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  80;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  80; Vers.    5:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1980/1DAY/PUB/
     -----DSS---ZCLOSE Unit:  80,    File: WETEXMPL.DSS
                Pointer Utilization:    .15
                Number of Records:    100
                File Size:    291.6  Kbytes
                Percent Inactive:     .0
NBVAL=           80NEVAL=          315
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  81;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  81; Vers.    2:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1981/1DAY/PUB/
     -----DSS---ZCLOSE Unit:  81,    File: WETEXMPL.DSS
                Pointer Utilization:    .15
                Number of Records:    100
                File Size:    291.6  Kbytes
                Percent Inactive:     .0
NBVAL=           79NEVAL=          314
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  82;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  82; Vers.    2:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1982/1DAY/PUB/
     -----DSS---ZCLOSE Unit:  82,    File: WETEXMPL.DSS
                Pointer Utilization:    .15
                Number of Records:    100
                File Size:    291.6  Kbytes
                Percent Inactive:     .0
NBVAL=           79NEVAL=          314
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  83;  DSS Version: 6-ND
-----DSS--- ZREAD Unit  83; Vers.    2:  /NOWHERE RIVER/LOST HIGHWAY BRIDGE/STAG
E/01JAN1983/1DAY/PUB/
     -----DSS---ZCLOSE Unit:  83,    File: WETEXMPL.DSS
                Pointer Utilization:    .15
                Number of Records:    100
                File Size:    291.6  Kbytes
                Percent Inactive:     .0
NBVAL=           79NEVAL=          314
     -----DSS---ZOPEN:  Existing File Opened,  File: WETEXMPL.DSS
                        Unit:  84;  DSS Version: 6-ND
```

Screen Shot of DOS Window During WETSORT Execution

APPENDIX - D
EXAMPLE PROBLEM
WETSORT ASCII
OUTPUT FILE

WETEXMPL.OUT

NOWHERE RIVER
LOST HIGHWAY BRIDGE

MONTH/DAY GROWING SEASON BEGINS 3/ 20
MONTH/DAY GROWING SEASON ENDS 11/ 10
NUMBER OF DAYS OF FIVE PERCENT DURATION = 15

			----STARTING---			-----ENDING----		
	STAGE	ELEV	MON	DAY	YR	MON	DAY	YR
	------	------	---	---	---	---	---	---
1	17.70	17.70	3	20	1971	4	3	1971
2	25.30	25.30	5	6	1972	5	20	1972
3	32.90	32.90	4	27	1973	5	11	1973
4	27.00	27.00	6	10	1974	6	24	1974
5	30.80	30.80	4	1	1975	4	15	1975
6	24.20	24.20	6	30	1976	7	14	1976
7	26.60	26.60	4	6	1977	4	20	1977
8	26.20	26.20	3	31	1978	4	14	1978
9	29.90	29.90	4	6	1979	4	20	1979
10	24.40	24.40	4	10	1980	4	24	1980
11	22.00	22.00	6	4	1981	6	18	1981
12	23.50	23.50	3	20	1982	4	3	1982
13	29.00	29.00	5	13	1983	5	27	1983
14	27.60	27.60	5	8	1984	5	22	1984
15	28.70	28.70	4	5	1985	4	19	1985
16	25.70	25.70	4	21	1986	5	5	1986
17	26.10	26.10	3	20	1987	4	3	1987
18	26.50	26.50	4	16	1988	4	30	1988
19	28.00	28.00	3	29	1989	4	12	1989
20	28.10	28.10	4	25	1990	5	9	1990

WETEXMPL2.OUT

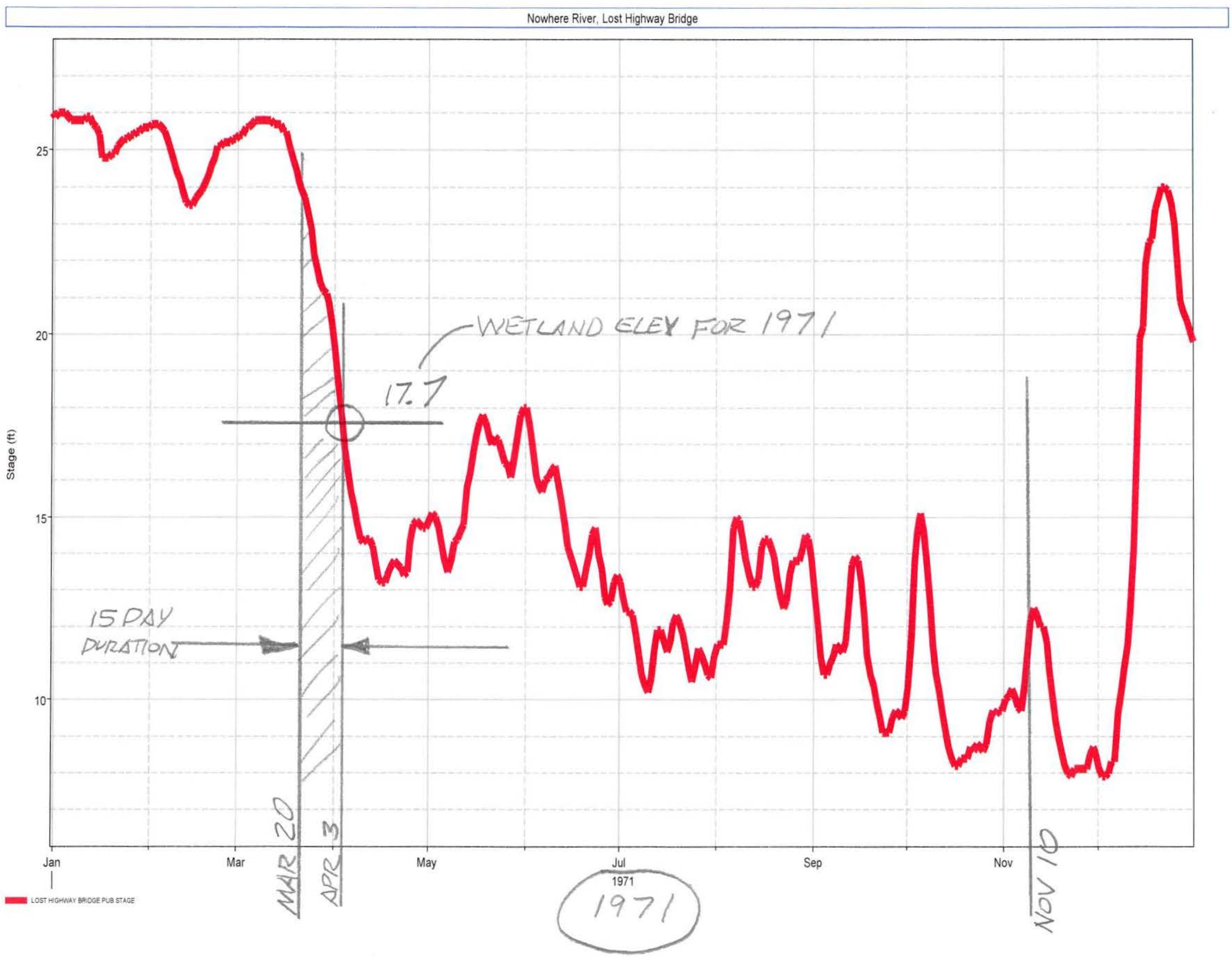
-----SORTED TABLE-----

NOWHERE RIVER
LOST HIGHWAY BRIDGE

MONTH/DAY GROWING SEASON BEGINS 3/ 20
MONTH/DAY GROWING SEASON ENDS 11/ 10
NUMBER OF DAYS OF FIVE PERCENT DURATION = 15

			----STARTING---			-----ENDING----		
	STAGE	ELEV	MON	DAY	YR	MON	DAY	YR
	------	------	---	---	---	---	---	---
1	32.90	32.90	4	27	1973	5	11	1973
2	30.80	30.80	4	1	1975	4	15	1975
3	29.90	29.90	4	6	1979	4	20	1979
4	29.00	29.00	5	13	1983	5	27	1983
5	28.70	28.70	4	5	1985	4	19	1985
6	28.10	28.10	4	25	1990	5	9	1990
7	28.00	28.00	3	29	1989	4	12	1989
8	27.60	27.60	5	8	1984	5	22	1984
9	27.00	27.00	6	10	1974	6	24	1974
10	26.60	26.60	4	6	1977	4	20	1977
11	26.50	26.50	4	16	1988	4	30	1988
12	26.20	26.20	3	31	1978	4	14	1978
13	26.10	26.10	3	20	1987	4	3	1987
14	25.70	25.70	4	21	1986	5	5	1986
15	25.30	25.30	5	6	1972	5	20	1972
16	24.40	24.40	4	10	1980	4	24	1980
17	24.20	24.20	6	30	1976	7	14	1976
18	23.50	23.50	3	20	1982	4	3	1982
19	22.00	22.00	6	4	1981	6	18	1981
20	17.70	17.70	3	20	1971	4	3	1971

APPENDIX - E
EXAMPLE PROBLEM
PLOT OF THE YEAR 1971



Nowhere River, Lost Highway Bridge
Stage (ft)
25
20
15
10
Jan
Mar
May
Jul
Sep
Nov
1971
LOST HIGHWAY BRIDGE PUB STAGE
WETLAND ELEV FOR 1971
17.7
15 DAY DURATION
MAR 20
APR 3
NOV 10
1971

APPENDIX - F
WETSORT FORTRAN 77
SOURCE CODE

```
      DIMENSION KYR(55,370),KMON(55,370),KDAY(55,370),YELEV(55,370),
     &SMAX(55),IBEGIN(55),NUMDAYS(55)
      CHARACTER OUTFILE*37
      CHARACTER STREAM*40
      CHARACTER LOC*40
      CHARACTER PAGE*2
  101 FORMAT(A)
      PRINT *,'ENTER YOUR OUTPUT FILENAME : '
      READ(*,101)OUTFILE
      NUM=2
      OPEN(NUM,FILE=OUTFILE)
      PRINT *,'ENTER STREAM NAME : '
      READ(*,101)STREAM
      PRINT *,'ENTER LOCATION OF GAGE : '
      READ(*,101)LOC
      PRINT *,'ENTER STARTING YEAR : '
      READ(*,*)IBYEAR
      PRINT *,'ENTER ENDING YEAR : '
      READ(*,*)IEYEAR
      PRINT *,'ENTER STARTING MONTH OF GROWING SEASON : '
      READ(*,*)IBMONTH
      PRINT *,'ENTER STARTING DAY OF GROWING SEASON : '
      READ(*,*)IBDAY
      PRINT *,'ENTER ENDING MONTH OF GROWING SEASON : '
      READ(*,*)IEMONTH
      PRINT *,'ENTER ENDING DAY OF GROWING SEASON : '
      READ(*,*)IEDAY
      PRINT *,'ENTER NUMBER OF DAYS OF FIVE PERCENT DURATION : '
      READ(*,*)IDUR
      PRINT *,'ENTER GAGE ZERO : '
      READ(*,*)GZ
      CALL GETDSS(IBMONTH,IBDAY,IBYEAR,IEMONTH,IEDAY,IEYEAR,YELEV
     &,KMON,KDAY,KYR,NUMDAYS)
C
C     COMPUTE VALUES
C
       WRITE(2,*)' '
       WRITE(2,*)'                       ',OUTFILE
       WRITE(2,*)' '
       WRITE(2,*)'    ',STREAM
       WRITE(2,*)'    ',LOC
       WRITE(2,*)'                       '
       WRITE(2,104)IBMONTH,IBDAY
       WRITE(2,106)IEMONTH,IEDAY
       WRITE(2,105)IDUR
       WRITE(2,*)' '
       WRITE(2,*)'                         ----STARTING---   -----ENDING-
     &---'
       WRITE(2,*)'        STAGE    ELEV   MON   DAY    YR   MON   DAY
     &YR'
       WRITE(2,*)'       ------  ------   ---   ---   ---   ---   ---
     &---'
      DO 30 K=1,IEYEAR-IBYEAR+1
         SMAX(K) = 0.
         DO 15 II=1,NUMDAYS(K)-(IDUR-1)
            SMIN = 10000.
            DO 20 KK=II,II+(IDUR-1)
               IF(YELEV(K,KK).LT.SMIN) SMIN = YELEV(K,KK)
```

```
   20       CONTINUE
            KK=KK-1
            IF(SMIN.GT.SMAX(K)) THEN
               SMAX(K) = SMIN
               IBEGIN(K) = KK-(IDUR-1)
            ENDIF
   15    CONTINUE
        WRITE(2,102) K,SMAX(K),SMAX(K)+GZ,KMON(K,IBEGIN(K)),
     &              KDAY(K,IBEGIN(K)),
     &              KYR(K,IBEGIN(K)),KMON(K,IBEGIN(K)+(IDUR-1)),
     &              KDAY(K,IBEGIN(K)+(IDUR-1)),KYR(K,IBEGIN(K)+(IDUR-1))
  102 FORMAT(I6,2F8.2,6I6)
   30 CONTINUE
C
C
C
C    SORT TABLE
C
C
      DO 160 M=1,IEYEAR-IBYEAR+1
        N=IEYEAR-IBYEAR+2-M
        DO 150 MM=1,N
        IF (SMAX(MM).GE.SMAX(MM+1)) GO TO 150
        SMAXT=SMAX(MM)
        KMONT=KMON(MM,IBEGIN(MM))
        KDAYT=KDAY(MM,IBEGIN(MM))
        KYRT=KYR(MM,IBEGIN(MM))
        KMONTT=KMON(MM,IBEGIN(MM)+(IDUR-1))
        KDAYTT=KDAY(MM,IBEGIN(MM)+(IDUR-1))
        KYRTT=KYR(MM,IBEGIN(MM)+(IDUR-1))
        SMAX(MM)=SMAX(MM+1)
        KMON(MM,IBEGIN(MM))=KMON(MM+1,IBEGIN(MM+1))
        KDAY(MM,IBEGIN(MM))=KDAY(MM+1,IBEGIN(MM+1))
        KYR(MM,IBEGIN(MM))=KYR(MM+1,IBEGIN(MM+1))
        KMON(MM,IBEGIN(MM)+(IDUR-1))=KMON(MM+1,IBEGIN(MM+1)+(IDUR-1))
        KDAY(MM,IBEGIN(MM)+(IDUR-1))=KDAY(MM+1,IBEGIN(MM+1)+(IDUR-1))
        KYR(MM,IBEGIN(MM)+(IDUR-1))=KYR(MM+1,IBEGIN(MM+1)+(IDUR-1))
        SMAX(MM+1)=SMAXT
        KMON(MM+1,IBEGIN(MM+1))=KMONT
        KDAY(MM+1,IBEGIN(MM+1))=KDAYT
        KYR(MM+1,IBEGIN(MM+1))=KYRT
        KMON(MM+1,IBEGIN(MM+1)+(IDUR-1))=KMONTT
        KDAY(MM+1,IBEGIN(MM+1)+(IDUR-1))=KDAYTT
        KYR(MM+1,IBEGIN(MM+1)+(IDUR-1))=KYRTT
  150 CONTINUE
  160 CONTINUE
C
C
C      WRITE OUT SORTED TABLE
C
C
       PAGE='\f'C
       WRITE(2,*)PAGE
       WRITE(2,*)' '
       WRITE(2,*)'                -----SORTED TABLE-----'
       WRITE(2,*)' '
       WRITE(2,*)'    ',STREAM
       WRITE(2,*)'    ',LOC
```

```
      WRITE(2,*)'                              '
      WRITE(2,104)IBMONTH,IBDAY
      WRITE(2,106)IEMONTH,IEDAY
      WRITE(2,105)IDUR
 104  FORMAT('     MONTH/DAY GROWING SEASON BEGINS  ',I3,'/',I3)
 105  FORMAT('     NUMBER OF DAYS OF FIVE PERCENT DURATION = ',I3)
 106  FORMAT('     MONTH/DAY GROWING SEASON ENDS  ',I3,'/',I3)
      WRITE(2,*)' '
      WRITE(2,*)' '
      WRITE(2,*)'                        ----STARTING---   -----ENDING-
     &---'
      WRITE(2,*)'        STAGE    ELEV   MON   DAY    YR   MON   DAY
     &YR'
      WRITE(2,*)'       ------  ------   ---   ---   ---   ---   ---
     &---'
C
      DO 170 K=1,IEYEAR-IBYEAR+1
      WRITE (2,102)K,SMAX(K),SMAX(K)+GZ,KMON(K,IBEGIN(K)),
     &             KDAY(K,IBEGIN(K)),
     &      KYR(K,IBEGIN(K)),KMON(K,IBEGIN(K)+(IDUR-1)),
     &      KDAY(K,IBEGIN(K)+(IDUR-1)),KYR(K,IBEGIN(K)+(IDUR-1))
 170  CONTINUE
C
C
C
     STOP
     END
C
     SUBROUTINE GETDSS(IBMONTH,IBDAY,IBYEAR,IEMONTH,IEDAY,IEYEAR,YELEV
    &,IMO,IDA,IYR,NUMDAYS)
     DIMENSION YELEV(55,366),IMO(55,366),IDA(55,366),IYR(55,366),
    &XELEV(366),NUMDAYS(55)
     CHARACTER CNAME*64,CNNAME*64,CTIME*4,CPATH*80
     LOGICAL LEXIST
     INTEGER IDAY(12)
     DATA IDAY / 31,28,31,30,31,30,31,31,30,31,30,31/
     PRINT *,'ENTER YOUR DSS FILENAME : '
 100 format (A)
     READ(*,100)CNAME
     CALL ZFNAME(CNAME,CNNAME,NNAME,LEXIST)
     IF(.NOT.LEXIST)THEN
        WRITE(*,*)'*** The DSS file does not exist. ***'
        STOP
     ENDIF
     PRINT *,'ENTER PATHNAME (no D part) :'
     READ(*,100)CPATH
     CTIME='2400'
     DO 231 NY=IBYEAR,IEYEAR
           CALL GETDSSDATA(CPATH,CTIME,IBMONTH,IBDAY,NY,IEMONTH,
    &                     IEDAY,NY,CNNAME,XELEV)
           NVAL=0
           IDAY(2)=28
           IF(INT(NY/4.0).EQ.(NY/4.0))IDAY(2)=29
           DO 232 NM=IBMONTH,IEMONTH
                 IF(NM.EQ.IBMONTH)THEN
                       BEGDA=IBDAY
                 ELSE
                       BEGDA=1
```

```
                  ENDIF
                  IF(NM.EQ.IEMONTH)THEN
                        ENDDA=IEDAY
                  ELSE
                        ENDDA=IDAY(NM)
                  ENDIF
                  DO 233 ND=BEGDA,ENDDA
                        NVAL=NVAL+1
                        YELEV(NY-IBYEAR+1,NVAL)=XELEV(NVAL)
                        IYR(NY-IBYEAR+1,NVAL)=NY
                        IMO(NY-IBYEAR+1,NVAL)=NM
                        IDA(NY-IBYEAR+1,NVAL)=ND
  233             CONTINUE
                  NUMDAYS(NY-IBYEAR+1)=NVAL
  232       CONTINUE
C
C
C            DO 887 I=1,NUMDAYS(NY-IBYEAR+1)
C                   WRITE(*,*)IMO(NY-IBYEAR+1,I),IDA(NY-IBYEAR+1,I),
C     &IYR(NY-IBYEAR+1,I),YELEV(NY-IBYEAR+1,I)
C  887       CONTINUE
C
C
  231 CONTINUE
      RETURN
      END
C
      SUBROUTINE GETDSSDATA(CPATH,CTIME,IBMONTH,IBDAY,IBYEAR,
     &IEMONTH,IEDAY,IEYEAR,CNNAME,DSSVALUES)
      DIMENSION DSSVALUES(5000)
      INTEGER IFLTAB(1200),NDATE,IDAY(12)
      INTEGER*4 IOFSET
      CHARACTER CNNAME*64,CDATE*20,CTIME*4,CUNITS*8,CTYPE*8,CPATH*80
      REAL VALUES(366)
      DATA IDAY / 31,29,31,30,31,30,31,31,30,31,30,31/
      CALL ZOPEN (IFLTAB,CNNAME,IOSTAT)
      IF(IOSTAT.NE.0)THEN
        WRITE(*,*)'*** Error opening DSS file ***'
        STOP
      ENDIF
      INUM=IEYEAR-IBYEAR
      IYEAR=IBYEAR
      IY=0
      II=0
 5005 IY=IY+1
 5006 CNT=1
      NVALS=365
      IF(INT(IYEAR/4.0).EQ.(IYEAR/4.0))NVALS=366
      JULS=IYMDJL(IYEAR,01,01)
      CALL JULDAT (JULS,104,CDATE,NDATE)
      CALL ZRRTS (IFLTAB,CPATH,CDATE,CTIME,NVALS,VALUES,
     *            CUNITS,CTYPE,IOFSET,ISTAT)
      CALL ZCLOSE(IFLTAB)
      IF(ISTAT.EQ.4.OR.ISTAT.EQ.5)THEN
        IYEAR=IYEAR+1
        IF(IYEAR.GT.IEYEAR)THEN
          IY=IY-1
          GOTO 999
```

```
        ENDIF
        GOTO 5006
      ELSEIF(ISTAT.GT.10)THEN
        WRITE(*,5010)ISTAT
        GOTO 999
      ENDIF
 5010 FORMAT(' A "fatal" error occurred in ZRRTS. ISTAT = ',I2)
      IDAY(2)=28
      IF(NVALS.EQ.366)IDAY(2)=29
      DO 800 MV=1,NVALS
        IF (VALUES(MV).EQ.-901.0.OR.VALUES(MV).EQ.-902.0) THEN
          MV2=MV
  801     IF (VALUES(MV2+1).EQ.-901.0.OR.VALUES(MV2+1).EQ.-902.0) THEN
            MV2=MV2+1
            GOTO 801
          ENDIF
          IF (MV.EQ.1.) THEN
            REPVAL=VALUES(MV2+1)
          ELSE
            REPVAL=(VALUES(MV-1)+VALUES(MV2+1))/2
          ENDIF
          DO 802 MV3=MV,MV2
            VALUES(MV3)=REPVAL
  802     CONTINUE
          IF (MV2-MV.GE.4) THEN
            WRITE(*,*)' '
            WRITE(*,*)'*** WARNING!!! - 5 or more consecutive missing va
     *lues! ***'
            WRITE(*,*)' '
          ENDIF
        ENDIF
  800 CONTINUE
  100 format (A)
      NBVAL=1
      NEVAL=NVALS
      IF(IYEAR.EQ.IBYEAR)THEN
         NUMDAYS=0
         DO 220 NM=1,12
            DO 221 ND=1,IDAY(NM)
               NUMDAYS=NUMDAYS+1
               IF((IBMONTH.EQ.NM).AND.(IBDAY.EQ.ND)) THEN
                  NBVAL=NUMDAYS
                  GOTO 228
               ENDIF
  221       CONTINUE
  220    CONTINUE
      ENDIF
  228 IF(IYEAR.EQ.IEYEAR)THEN
         NUMDAYS=0
         DO 222 NM=1,12
            DO 223 ND=1,IDAY(NM)
               NUMDAYS=NUMDAYS+1
               IF((IEMONTH.EQ.NM).AND.(IEDAY.EQ.ND)) THEN
                  NEVAL=NUMDAYS
                  GOTO 229
               ENDIF
  223       CONTINUE
  222    CONTINUE
```

```
      ENDIF
 229  WRITE(*,*)'NBVAL=',NBVAL,'NEVAL=',NEVAL
      DO 250 NVAL = NBVAL,NEVAL
           II=II+1
           DSSVALUES(II) = VALUES(NVAL)
  250 CONTINUE
      IYEAR=IYEAR+1
      IF(IYEAR.LE.IEYEAR)GOTO 5005
C 999 CALL ZCLOSE(IFLTAB)
  999 RETURN
      END

      SUBROUTINE EXIST (FNI)
      CHARACTER FNI*37,AL*80
    5 OPEN (4,FILE=FNI)
      READ(4,20,END=48)AL
   20 FORMAT(A)
      CLOSE(4)
      RETURN
   48 WRITE(*,40)
   40 FORMAT(' File does not exist.')
   10 FORMAT (' Enter correct filename using proper specs :')
      WRITE (*,10)
      READ(*,20)FNI
      CLOSE(4,STATUS='DELETE')
      GOTO 5
      END

      SUBROUTINE OVERWRITE (FNO,NUM)
      CHARACTER FNO*37,AL*80,QQ*1
    5 OPEN (NUM,FILE=FNO)
   20 FORMAT (A)
      READ(NUM,20,END=48)AL
   40 FORMAT(' File exists, overwrite it? (Y/N)')
   45 WRITE(*,40)
      READ(*,20)QQ
      IF(QQ.EQ.'Y'.OR.QQ.EQ.'y')GOTO 48
      IF(QQ.EQ.'N'.OR.QQ.EQ.'n') THEN
   30   FORMAT(' Enter new filename :')
        WRITE(*,30)
        READ(*,20)FNO
        GOTO 5
      ENDIF
      GOTO 45
   48 CLOSE(NUM,STATUS='DELETE')
      OPEN(NUM,FILE=FNO)
      RETURN
      END
```

Appendix M
Part 3

GIS Applications for Elevations

U.S. Army Corps of Engineers
Memphis District

Existing data was used to develop contour elevations for the project. U.S. Geological Survey 10-meter Digital Elevation Models (DEM) were obtained from the U.S. Department of Agriculture Geospatial Data Clearinghouse (http://datagateway.nrcs.usda.gov/).A DEMs was obtained for each specific quadrangle[1] map that comprised a portion of the St. Johns Bayou Basin. The DEMs were mosaiced together and then clipped to the overall St. Johns Bayou Basin limits.

USACE previously developed a DEM along the Mississippi River that included the batture area and the New Madrid Floodway by utilizing LIDAR. Applicable project area data was extracted from this overall data set that represented the boundary of the New Madrid Floodway.

Once the data was assembled, the following procedure was conducted to establish contours within the project area:

1. One-foot contours were developed with ArcGIS 9.3, ArcToolbox, Spatial Analyst Tools, Reclassify tool. This resulted in reclassification of the previous data sets into one-foot contours.
2. The reclassified DEM was converted into a polyline utilizing the Contour Tool within Spatial Analyst.
3. Geometry was repaired utilizing ArcGIS 9.3, ArcToolbox, Data Management Tools, Features, Repair Geometery. The input shapefile was each particular contour of interest. This step repaired the polyline coverage and allowed polygons to be created. The following geometry issues were repaired:
    a. Null geometry – The feature will be deleted from the feature class.
    b. Short segment – The geometry's short segment will be deleted.
    c. Incorrect ring ordering – The geometry will be updated to have correct ring ordering.
    d. Incorrect segment orientation – The geometry will be updated to have correct segment orientation.
    e. Self intersections – The geometry's segments that intersect will be split at their intersection.
    f. Unclosed rings – The unclosed rings will be closed.
    g. Empty parts – The parts that are null or empty will be deleted.
4. Once the feature repair geometry step was complete, ArcGIS 9.3, ArcToolbox, Data Management Tools, Features, Feature was accessed to create a polygon coverage from the polyline coverage. The input feature was the particular contour of interest with the output feature class being the polygon coverage created from the input polyline coverage. After the polygon coverage was created, merged individual polygons were created for each particular contour interval.

[1] Specific USGS quad maps are as follows: Anniston, Bayouville, Betrand, Cache, Cairo, Chaffee, Charleston, Charter Oak, East Prairie, Henderson, Hubbard Lake, Kewanee, Morehouse, Morley, New Madrid, Oran, Scott City, Sikeston North, Sikeston South, Thebes, Thebes SW, Vanduser, Wickliffe SW, and Wyatt.

Appendix M
Part 4

Assessment of DEM Accuracy on the St. Johns New Madrid Shorebird Habitat Model

U.S. Army Corps of Engineers
Memphis District

Assessment of Digital Elevation Model Accuracy on the St. John's – New Madrid Shorebird Habitat Model

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Problem
The SJNM Shorebird Model was developed using the best available elevation data for the study area; a LIDAR (LIght Detection And Ranging) derived DEM was available for the New Madrid portion of the study area, while a 10m USGS DEM was available for the St. John's portion of the study area. During the review of the model (Battelle, 2011), the question of the appropriateness of the lower quality elevation data (10m USGS DEM) was raised.

Purpose
The purpose of this study is to assess the effect of digital elevation model (DEM) accuracy on the model parameters calculated for the Shorebird Habitat Model developed for the St. John's – New Madrid basin (SJNM), Missouri.

Goal
Although the primary purpose of this study is to determine the effect of DEM accuracy on the model parameters used in the SJNM Shorebird Habitat Model, the findings of this study apply to a wide range of DEM usage within the US Army Corps of Engineers (USACE). Therefore, this study will examine not only the particular DEM used in the development of the SJNM Shorebird Habitat Model, but will also examine a range of common DEM products and resolutions with the goal of developing practical guidelines to better inform practitioners in the application of DEMs to common USACE tasks.

Objectives
1. Determine the vertical accuracy of the 10m USGS DEM compared to the LIDAR derived DEM.
2. Conduct a sensitivity analysis to measure the effect of DEM inaccuracy on total estimated shorebird habitat.

Shorebird Model Approach
Based on a brief literature review, I believe that the modeling approach chosen for the SJNM Shorebird Habitat Model is a novel method and an extremely adaptable technique for estimating shorebird habitat using readily available DEMs, land cover classifications, and aerial photography. As with all spatial habitat models, a critical issue is: What is the finest resolution that the habitat can be mapped with existing data? Therefore, the challenge for applying this new modeling technique is to determine the finest spatial resolution that existing DEMs can support.

The strategy used by this approach is to incrementally raise the water level across the study area and record the newly inundated area at each step (while applying habitat quality factors), adding it to the total (as in integral calculus). Since one of the primary purposes of the model is to generate a habitat mitigation estimate, this technique is particularly appropriate in that only a single total area of shorebird habitat is required. Rather than a spatially explicit habitat suitability map, only a single area estimate is required.

One interesting possibility is that this high degree of aggregation could make the proposed total inundated area metric extremely robust to DEM inaccuracy. Even if the DEM is relatively inaccurate, the total inundated area metric may not be sufficiently sensitive to this inaccuracy to cause marked fluctuations in the final metric. Although Twedt did not express the advantages of the metric in exactly this way, he clearly describes the approach's advantages (Twedt, 2010, p 4., my emphasis added):

> Assumptions and Rationale –
>
> 1. The contour lines developed by USACE, Memphis District that are associated with 1-foot increments in Mississippi River stage, as recorded at the New Madrid gauge, *provide a reasonably accurate representation of the floodwater extent associated with each of these river stages.*

2. Use Geographic Information System (GIS) to derive interpolated elevations between 1-foot contour lines at <1-foot intervals (e.g., at 2 inch [5 cm], 4 inch [10 cm], or 0.1 foot [3 cm] intervals) so as to depict the theoretical distribution of floodwater extent associated with Mississippi River stages between the 1 foot river stages.
   a. Where possible, interpolation will be aided by LIDAR and DTM data. Elsewhere, interpolations will be based only on distance between contour lines.
   b. *Although distance interpolation may be imprecise, the assumption is that variation in flood area is averaged, thereby providing a reasonable approximation of the flooded area. Thus, this representation may not depict the exact geographic distribution of flooding but the total area inundated is presumed accurate.*

The essence of the approach is to incrementally raise the water across a DEM and record the inundated area at each step. As in integral calculus, the step-increment is chosen arbitrarily small to obtain an accurate overall estimate of the total volume, not because the step-increment is relevant to the application or the accuracy of the data. Too small of a step-increment and computational time is unnecessarily wasted, while too coarse of a step and estimate resolution is lost. Therefore, the question for this type of model is not whether a DEM will support 0.1 foot contours, but whether the calculation of a metric of this type requires a 0.1 foot step-increment to obtain a meaningful estimate of shorebird habitat.

As an ornithologist, and not a GIS analyst, Twedt's explanation of the GIS portion of the methodology is somewhat ambiguous and therefore potentially misleading. I believe a lack of documentation of the GIS methods has created much of the misunderstanding surrounding the review of this model. Because I was unable to find any detailed or specific description of the actually data processing steps used, I developed an approach (as there are always many) to operationalize and test the approach he describes.

Available DEMs
The question of the best available elevation data is always complicated by three main factors: 1. data collection methods, 2. availability date, and 3. areal extent. Usually there is not a perfect coincidence of these three factors and compromise is always necessary. The table below describes the DEMs available for this study area.

DEM	Elevation Collection Method	Source Agency	Areal Extent	Ground Condition	DEM Available
Lidar	LIDAR, breaklines, hydrographic cross-sections	USACE, PhotoScience	Mississippi River, Memphis District	2004	2004 (?)
DEM10	digitized USGS 7.5 Quandrangle hypsography, spot elevations, hydrography	USGS, Univ. of Missouri-Columbia, CARES	Missouri	1969	2003
NED10	Photogrammetric mass points, breaklines	USGS, NED	New Madrid Floodway	1995	2008
NED30	Photogrammetric mass points, breaklines	USGS, NED	New Madrid Floodway	1995	2008

Table 1. Characteristics of Available DEMs.

Although LIDAR typically has the highest quality (spatial resolution and elevation accuracy), it is often not available for the entire study area. In this case, LIDAR (flown for USACE in 2004) is available for the New Madrid portion of the study area, but not for the St. John's portion. For the St. John's portion of the study area, the best available elevation data is a DEM based on digitized USGS 7.5 Quadrangle hypsography (contour lines), spot elevations, and hydrography. This DEM is abbreviated as DEM10 in this analysis. This is one of the most common techniques used by USGS to generate DEMs throughout the U.S. when no better source of elevation data (photogrammetric mass points and breaklines, or LIDAR) is available. In 1995, USACE acquired elevation data (photogrammetric mass point and breaklines) for the New Madrid portion of the study area (but not for the St. John's) and this has now (since 2008) been incorporated into the USGS National Elevation Dataset (NED). Since the NED now uses best available data to build its NED products, the 10m (1/3rd arc-second), and 30m (one arc-second) NED products currently (April, 2011 version) use this 1995 elevation data as its source for the New Madrid portion of the study area. Apparently, the 2004 LIDAR dataset has not been incorporated by the USGS into the generation of the 10m or 30m NED at the time of this writing.

Therefore, based on this availability of DEMs, the Shorebird Model was developed using LIDAR source data for New Madrid and digitized USGS contours, spot elevations, and hydrography for the St. John's portion. These two data sources potentially represent opposite ends of the spectrum of DEM source data quality and create a problem of differing elevation data quality across the single SJNM study area. The question this analysis will attempt to answer is to determine the effect of this difference in DEM quality on the calculation of the shorebird habitat metric. That there is a difference in elevation accuracy between the DEMs is not as important to the review of the SJNM Shorebird Model as is the question of whether that difference in elevation accuracy substantially affects the shorebird habitat metric.

Key Study Question

Can DEMs derived from digitized USGS 7.5 Quadrangle hypsography, spot elevations, and hydrography (best available for SJ) produce similar results for the shorebird habitat metric as LIDAR derived DEMs (best available for NM)?

Methods

The analysis strategy employed in this study used the highest quality elevation source data available (Lidar) as the most accurate estimate of the true elevation. Other DEMs were then compared against this definition of the "true" elevation. Since LIDAR is available only for the NM portion of the study area, this study will focus analysis on the NM portion of the SJNM study area. This study examines the accuracy of the available DEMs for the NM study area, including the DEM derived from digitized USGS 7.5 Quadrangle hypsography, spot elevations, and hydrography (DEM10) which is the best available DEM for the SJ study area. By comparing these different types of DEMs in the NM study area, conclusions will be drawn about the relative suitability of various DEMs for calculating the shorebird habitat metric.

Analysis was performed using ESRI ArcGIS Desktop 10, Spatial Ecology's Geospatial Modeling Environment, and the R Language and Environment for Statistical Computing. All datasets used in this analysis and detailed process step documentation are available upon request from the author.

All DEMs were resampled to the same grid size (3 meters) using nearest neighbor resampling to preserve the original elevation values from the source DEMs. This was done to eliminate spatial resolution differences during the sensitivity analysis.

DEM accuracy assessment was performed using several methods. First, an effort was made to measure the accuracy of DEMs used in this study using National Geodetic Survey (NGS) high accuracy ground surveys (Order I). The Root Mean Squared Error (RMSE) statistic and boostrapped 95% confidence intervals (elevations were not normally distributed) were calculated to measure the difference between the 61 NGS control points available for the NM study area and the DEM values for each elevation grid (Table 2). Second, difference grids were calculated to measure the difference of each DEM from the Lidar grid and allow visual examination of the spatial distribution of error (Figure 1). Descriptive statistics, the RMSE, and boostrapped 95% confidence intervals (elevation data was not normally distributed) are reported in Table 3.

The shorebird habitat metric sensitivity analysis was achieved by calculating the amount of area inundated at each 0.1 foot increments and recording the marginal and cumulative area inundated at each step. An Python script was written using the ESRI ArcGIS Desktop 10 ArcPy API to model inundation. This script was run for each DEM in this study and results were imported into R for statistical analysis and graphing. Graphs of marginal (Figure 2) and cumulative inundated area (Figure 3) were created. Error statistics for marginal (Table 4) and cumulative inundated area (Table 5) were calculated with RMSE and boostrapped 95% confidence intervals (inundated areas were not normally distributed) being reported.

DEM Accuracy Assessment

NGS survey control points were used to measure the accuracy of DEMs used in this study (Table 2). These vertical accuracy calculations seem to indicate that the Lidar DEM is relatively inaccurate (2.11 ft RMSE). However, only a limited number of survey control points (61 1st Order) were available for the NM study area and the majority were not located in ideally flat terrain. Since many survey control points came from top-of-levee surveys, small horizontal displacements may cause the error statistic to be artificially inflated.

DEM	RMSE (ft)	95% C.I. Lower Bound (ft)	95% C.I. Upper Bound
Lidar	2.11	1.61	2.61
DEM10	2.23	1.69	2.83
NED30	2.77	2.31	3.22
SRTM	4.23	3.80	4.68

Table 2. Error statistics of various DEMs compared to 61 1st Order NGS survey control points. Root Mean Square Error (RMSE). 95% confidence interval calculated using bootstrapping functions found in the boot package for R. SRTM refers to Shuttle Radar Topography Mission, 90m pixel DEM.

Calculating the difference between the LIDAR derived DEM and the 10m DEMs provides an important visual and statistical picture of the accuracy of the DEMs relative to the LIDAR derived DEM. These maps highlight the spatial variability of elevation accuracy. Values close to zero indicate low difference (i.e., high accuracy, symbolized by yellows and greens on the map), higher values indicate high difference (i.e, low accuracy, positive values symbolized by red where the Lidar elevations are higher, and negative values symbolized by blue where the Lidar elevations are lower).

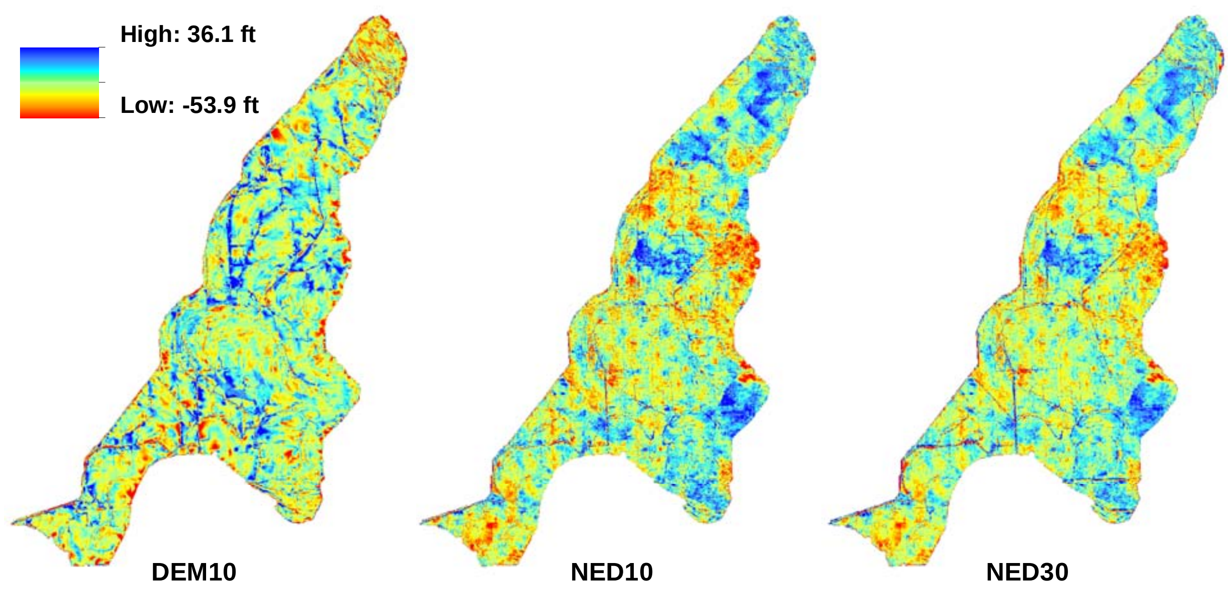

Figure 1. Differences between LIDAR derived DEM and other DEMS

Similarities in the spatial distribution of error between NED10 and NED30 are due to the fact that they are both derived from the same source data (1995 Photogrammetric mass points and breaklines). The differences between the NED DEMs and the DEM10 are due to the fact that it was derived from an entirely different set of source data (1969 digitized USGS 7.5 Quadrangle hypsography, spot elevations, and hydrography).

DEM	Min (ft)	Max (ft)	Mean (ft)	Standard Deviation (ft)	RMSE (ft)	95% C.I. Lower Bound (ft)	95% C.I. Upper Bound
DEM10	-52.53	36.14	-0.27	2.35	2.36	2.24	2.47
NED10	-51.11	25.38	-0.86	1.34	1.57	1.50	1.65
NED30	-53.86	30.36	-0.86	1.55	1.78	1.65	1.91

Table 3. Elevation differences of three DEMs from LIDAR derived DEM. Root Mean Square Error (RMSE). 95% confidence interval calculated using bootstrapping functions found in the boot package for R.

The newer 10m and 30m NED DEMs have means of -0.86 ft and a standard deviation of 1.34 ft and 1.55 ft respectively, while the older 10m DEM has a mean of -0.27 ft and a standard deviation of 2.35 ft. The three DEMs have means relatively close to zero, but the older DEM (DEM10) has greater spread around zero (indicated by the higher standard deviation) than the newer NED DEMs. The standard deviation indicates that for the newer NED10 and NED30 DEMs, ~66% of elevation values are less than 1.34 ft and 1.55 ft different than the LIDAR derived elevation. For the older DEM10, the standard deviation is 2.35 ft. This higher standard deviation indicates a higher degree of inaccuracy in the older 10m DEM when compared with the newer NED DEMs. The RMSE statistics in Table 3 also indicate that the DEM10 DEM is less accurate (RMSE 2.36 ft) than either the NED10 (RMSE 1.57 ft) or NED30 (RMSE 1.78 ft) elevation models.

Shorebird Habitat Metric Sensitivity Analysis

Since the DEM is being used to derive the shorebird habitat metric, a study of the appropriateness of a DEM must focus on the effects of DEM accuracy on the metric in question. The sensitivity analysis portion of this study developed a script to calculate a marginal and cumulative inundated area metric similar to the shorebird habitat metric. However, due to time limitations, this study did not carry the analysis beyond the area calculation step to apply the habitat quality weight factors. It was deemed sufficient for the purpose of assessing DEM accuracy requirements to stop at the evaluation of area, although testing effects on habitat quality would be fruitful if the model will be used more broadly.

The first step of the sensitivity analysis was to calculate the marginal inundated area at each 0.1 foot water level increments. Figure 2 displays the results of this analysis. This simulation raised the water level in 0.1 foot increments across each DEM (y-axis) and the marginal amount of land inundated at each step was recorded (x-axis). The Lidar DEM represented the highest spatial accuracy dataset and other DEMs were compared to this standard. In Figure 2, notice the distinctive error signature present in the DEM10 dataset. The clue to the source of this artifact is that the spikes are spaced at round 5 foot elevation intervals (285 ft, 290 ft, 295 ft, 300 ft, etc.). Upon further investigation, it was determined that these elevation intervals coincide with the contour intervals on the USGS Quadrangle sheet this DEM was derived from. The pattern in this graph results from DEMs derived from digitized USGS 7.5 Quandrangle hypsography (contour lines), spot elevations, and hydrography (streams/lakes/rivers). Identified as a common problem in NED DEMs, this effect is often referred to as terracing or ringing. This error structure is of particular because it is present in the best available DEM for the SJ portion of the study area.

The problem with this type of DEM error structure is that the inundated area estimate accuracy varies with elevation. A water elevation that happens to fall on one of the elevation contours (285, 290, 295, 300 ft, etc.) will overestimate the inundated area, while water levels that fall midway between the contour lines (287.5, 292.5, 297.5, 302.5 ft., etc.) will underestimate the inundated area. The error in inundated area estimated at any water elevation can be measured as the x-axis (inundated area) distance between the DEM10 line and the Lidar line. When the Lidar and DEM10 lines cross the inundated area estimates are the same.

The inundated area estimates for NED10 and NED30 track very closely in Figure 2 due to the fact that they are derived from the same underlying source data (photogrammetric mass points and breaklines). This is an interesting finding since it demonstrates that a coarser spatial resolution DEM (NED30, 30 m pixels) produces a similar inundated area estimate as a finer spatial resolution DEM (NED10, 10 m pixels), thus saving storage and computation time. Notice that the NED10 or NED30 DEMs derived from photogrammetric mass points and breaklines contain no apparent error structures in Figure 2. However, the NED10 and NED30 DEMs do possess a spatial error structure evidenced as a grid shape in Figure 1 (presumably the result of photogrammetric data processing methods used). This photogrammetric error structure is not obviously apparent in Figure 2.

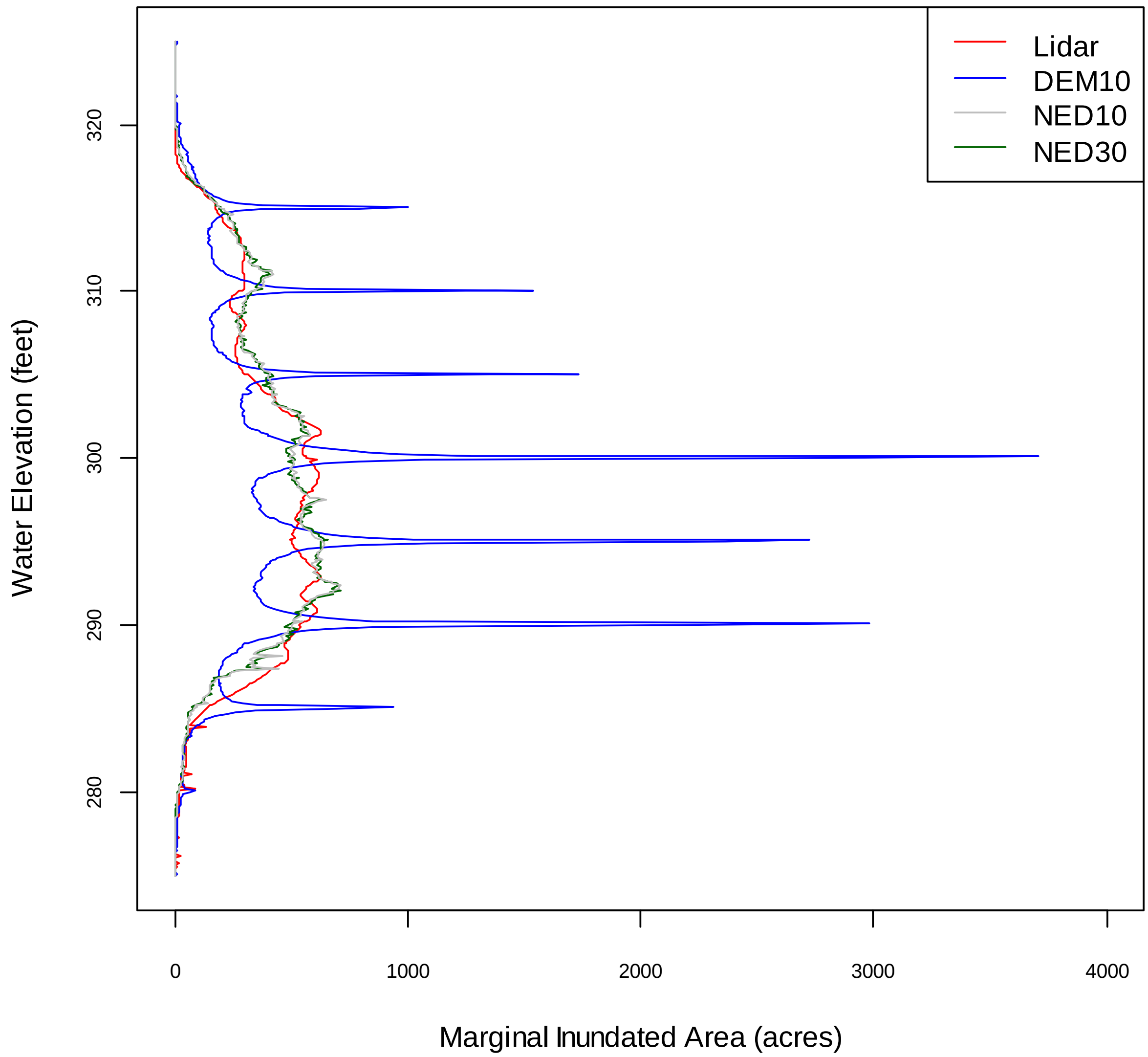

Figure 2. Marginal Inundated Area for several DEMs.

The next step in the sensitivity analysis was to calculate the cumulative inundated area at each 0.1 foot water level increments. Cumulative inundated area is the critical metric (not marginal inundated area) since the shorebird habitat metric accumulates the area inundated each day through the shorebird migration season. Figure 3 displays the results for this simulation as water levels are raised in 0.1 foot increments across each DEM (y-axis) and the cumulative amount of land inundated up to that water level was recorded (x-axis).

The significant observation from Figure 3 is that the estimates of cumulative inundated area for all DEMs roughly track the Lidar DEM, without major deviations. Despite the error structure present in the graph for the DEM10 marginal inundated area, that error structure does not affect the cumulative inundated area estimate. The DEM10 estimate follows the Lidar line as it periodically under- and then over-estimates cumulative inundated area, as discussed above. Again, the NED10 and NED30 datasets closely track each other as discussed above, but consistently overestimate the cumulative inundated area.

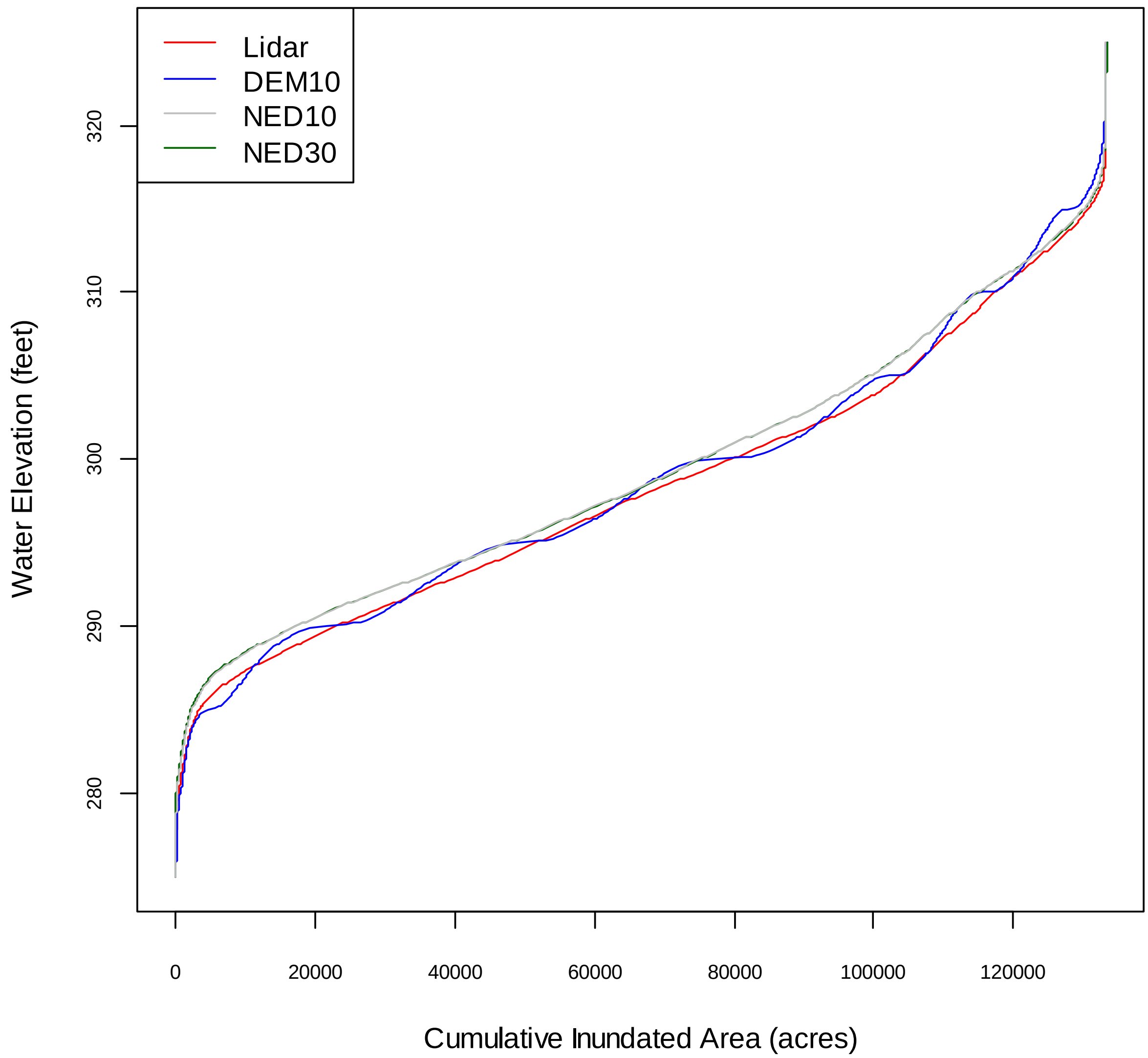

Figure 3. Cumulative Inundated Area for several DEMs.

DEM	RMSE	95% confidence interval lower bound	95% confidence interval upper bound
DEM10	312.9	222	408
NED10	56.5	52	61
NED30	57.4	53	62

Table 4. Error statistics of marginal inundated area (acres) of various DEMs vs. the Lidar DEM. Root Mean Square Error (RMSE). 95% confidence interval calculated using bootstrapping functions found in the boot package for R.

DEM	RMSE	95% confidence interval lower bound	95% confidence interval upper bound
DEM10	1,929	1,799	2,072
NED10	3,115	2,965	3,271
NED30	3,108	2,936	3,270

Table 5. Error statistics of cumulative inundated area (acres) of various DEMs vs. the Lidar Root Mean Square Error (RMSE). DEM. 95% confidence interval calculated using bootstrapping functions found in the boot package for R.

Analysis of the root mean squared error statistics for marginal and cumulative inundated areas reveals a similar pattern as the graph interpretation above. Although DEM10 has a higher marginal inundated area RMSE statistic (less accurate) than the NED DEMs (312 acres vs. ~57 acres), the DEM10 has a lower cumulative inundated area RMSE statistic (more accurate) than the NED DEMs (1,900 acres vs. 3,100 acres).

Discussion

The question of whether the DEM available for the SJ portion of the study area (similar to DEM10) can produce comparable estimates of shorebird habitat as a LIDAR derived DEM I believe is quantified by the results presented in Table 5. Despite DEM10 being a less accurate DEM than other DEMs (Table 3), and despite DEM10 having a peculiar error structure evidenced in marginal area calculations (Table 4), the aggregation of marginal inundation area estimates into a single cumulative inundated area metric largely erased these lower level errors. Constructing a metric from many incremental estimates is the basis of integral calculus and a common strategy in simulation. Unfortunately people are often only aware of the case of error propagation, but this is a classic case of the data analysis strategy of using aggregation to escape the low data resolution problem. This strategy seeks to escape the low resolution problem by moving up a scale level. Often this strategy provides a new way forward. By aggregating a large number of low spatial resolution estimates of inundated area into a single aspatial metric, based on the finds of this analysis, it appears that a single shorebird habitat estimate can be calculated.

Table 5 also indicates the uncertainty associated with these estimates and can be used to adjust habitat mitigation quantities. For example, rather than bear the added expense and delay to fly LIDAR, the shorebird habitat estimated for the SJ portion of the study area using a DEM similar to DEM10 could simply adjust its mitigation area estimate upward by the 95% confidence interval value. Model development using available data is the norm since the ideal data is seldom available.

Given the availability of LIDAR derived DEMs and their stunning quality relative to the USGS contour line derived DEMs of the recent past, I believe there was sufficient basis for concern about the use of these older DEMs is such flat terrain and being used for inundation mapping. The author's interest in this question stemmed from the numerous flood-fighting inundation mapping accuracy questions that have been raised recently. Complex metrics such as the shorebird habitat metric involve so many calculations with varying factors that compelling theories could be invoked to advocate for either error propagation or error reduction outcomes. Ultimately, only a test calculation can determine how all of the competing theories and effects will work out in the final metric.

Recommendations

1. Far from being within the purview of only a single discipline, effective habitat modeling requires the knowledge and expertise of several disciplines that no one individual can possibly hope in a lifetime to possess. Effective habitat modeling requires an interdisciplinary team of individuals that command the varied skills of biology, ecology, geospatial methods, statistics, and simulation and modeling.

2. Involving experts with the above full range of skills from the beginning of the model design phase onward is the most cost effective method of model development. Trying to fix issues that are the result of a flawed design after the fact or could have been resolved early is frustrating and inefficient.

3. Effective documentation of the detailed data processing steps used in this analysis and made available during the peer review phase would likely have eliminated much of the confusion and misinformation surrounding the subject of DEM accuracy.

References

Battelle Memorial Institute (2011) *Draft Planning Model Quality Assurance Review Report for the Model Review of the Assessment of Shorebird Habitat within the St. Johns-New Madrid Basins, Missouri.* U.S. Army Corps of Engineers Ecosystem Restoration Planning Center of Expertise, Memphis District, Contract No. W912HQ-10-D-002, Task Order: 0008

Gesch, D.B. (2007) Chapter 4 – The National Elevation Dataset, in Maune, D., ed., *Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition*: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.

Twedt, DJ. 2010, Assessment of Shorebird Habitat within the St. Johns-New Madrid Basins, Missouri. Study Plan 2302-9S270. USGS Patuxent Wildlife Research Center, Vicksburg, MS. 26 pp.

Appendix M
Part 5

Farmland Impact Conversion Rating Form AD-1006 (10-83)

U.S. Army Corps of Engineers
Memphis District

U.S. Department of Agriculture

FARMLAND CONVERSION IMPACT RATING

PART I *(To be completed by Federal Agency)*	Date Of Land Evaluation Request 6/16/11
Name Of Project St. Johns Bayou & New Madrid Floodway	Federal Agency Involved U.S. Army Corps of Eng., Memphis district
Proposed Land Use Flood Risk Mgt.	County And State New Madrid, MO
PART II *(To be completed by NRCS)*	Date Request Received By NRCS 6/16/11

Does the site contain prime, unique, statewide or local important farmland? *(If no, the FPPA does not apply -- do not complete additional parts of this form).*	Yes ☑ No ☐	Acres Irrigated	Average Farm Size
Major Crop*(s)* Corn	Farmable Land In Govt. Jurisdiction Acres: 410,855 %	Amount Of Farmland As Defined in FPPA Acres: 390,466 90 %	
Name Of Land Evaluation System Used LESA	Name Of Local Site Assessment System XXXXXXXX	Date Land Evaluation Returned By NRCS 6/23/11	

PART III *(To be completed by Federal Agency)*		Alternative Site Rating			
		Site A	Site B	Site C	Site D
A. Total Acres To Be Converted Directly		322.0	268.0		
B. Total Acres To Be Converted Indirectly		0.0	0.0		
C. Total Acres In Site		322.0	268.0	0.0	0.0
PART IV *(To be completed by NRCS)* Land Evaluation Information					
A. Total Acres Prime And Unique Farmland		8.0	8.0		
B. Total Acres Statewide And Local Important Farmland		0.0	0.0		
C. Percentage Of Farmland In County Or Local Govt. Unit To Be Converted		0.0	0.0		
D. Percentage Of Farmland In Govt. Jurisdiction With Same Or Higher Relative Value		94.5	94.5		
PART V *(To be completed by NRCS)* Land Evaluation Criterion Relative Value Of Farmland To Be Converted *(Scale of 0 to 100 Points)*		68	68	0	0
PART VI *(To be completed by Federal Agency)* Site Assessment Criteria *(These criteria are explained in 7 CFR 658.5(b)*	Maximum Points				
1. Area In Nonurban Use		15	15		
2. Perimeter In Nonurban Use		10	10		
3. Percent Of Site Being Farmed		20	20		
4. Protection Provided By State And Local Government		20	20		
5. Distance From Urban Builtup Area		10	10		
6. Distance To Urban Support Services		0	0		
7. Size Of Present Farm Unit Compared To Average		5	5		
8. Creation Of Nonfarmable Farmland		0	0		
9. Availability Of Farm Support Services		0	0		
10. On-Farm Investments		0	0		
11. Effects Of Conversion On Farm Support Services		0	0		
12. Compatibility With Existing Agricultural Use		0	0		
TOTAL SITE ASSESSMENT POINTS	160	80	80	0	0
PART VII *(To be completed by Federal Agency)*					
Relative Value Of Farmland *(From Part V)*	100	68	68	0	0
Total Site Assessment *(From Part VI above or a local site assessment)*	160	80	80	0	0
TOTAL POINTS *(Total of above 2 lines)*	260	148	148	0	0

Site Selected:	Date Of Selection 6/16/11	Was A Local Site Assessment Used? Yes ☐ No ☒

Reason For Selection:

(See Instructions on reverse side)

This form was electronically produced by National Production Services Staff

Clear Form

Form AD-1006 (10-83)

STEPS IN THE PROCESSING THE FARMLAND AND CONVERSION IMPACT RATING FORM

Step 1 – Federal agencies involved in proposed projects that may convert farmland, as defined in the Farmland Protection Policy Act (FPPA) to nonagricultural uses, will initially complete Parts I and III of the form.

Step 2 – Originator will send copies A, B and C together with maps indicating locations of site(s), to the Natural Resources Conservation Service (NRCS) local field office and retain copy D for their files. (Note: NRCS has a field office in most counties in the U.S. The field office is usually located in the county seat. A list of field office locations are available from the NRCS State Conservationist in each state).

Step 3 – NRCS will, within 45 calendar days after receipt of form, make a determination as to whether the site(s) of the proposed project contains prime, unique, statewide or local important farmland.

. Step ‘4 – In cases where farmland covered by the FPPA will be converted by the proposed project, NRCS field offices will complete Parts II, IV and V of the form.

Step 5 – NRCS will return copy A and B of the form to the Federal agency involved in the project. (Copy C will be retained for NRCS records).

Step 6 – The Federal agency involved in the proposed project will complete Parts VI and VII of the form.

Step 7 – The Federal agency involved in the proposed project will make a determination as to whether the proposed conversion is consistent with the FPPA and the agency’s internal policies.

INSTRUCTIONS FOR COMPLETING THE FARMLAND CONVERSION IMPACT RATING FORM

Part I: In completing the "County And State" questions list all the local governments that are responsible for local land controls where site(s) are to be evaluated.

Part III: In completing item B (Total Acres To Be Converted Indirectly), include the following:

1. Acres not being directly converted but that would no longer be capable of being farmed after the conversion, because the conversion would restrict access to them.

2. Acres planned to receive services from an infrastructure project as indicated in the project justification (e.g. highways, utilities) that will cause a direct conversion.

Part VI: Do not complete Part VI if a local site assessment is used.

Assign the maximum points for each site assessment criterion as shown in § 658.5 (b) of CFR. In cases of corridor-type projects such as transportation, powerline and flood control, criteria #5 and #6 will not apply and will, be weighed zero, however, criterion #8 will be weighed a maximum of 25 points, and criterion #11 a maximum of 25 points.

Individual Federal agencies at the national level, may assign relative weights among the 12 site assessment criteria other than those shown in the FPPA rule. In all cases where other weights are assigned relative adjustments must be made to maintain the maximum total weight points at l60.

In rating alternative sites, Federal agencies shall consider each of the criteria and assign points within the limits established in the FPPA rule. Sites most suitable for protection under these criteria will receive the highest total scores, and sites least suitable, the lowest scores.

Part VII: In computing the "Total Site Assessment Points" where a State or local site assessment is used and the total maximum number of points is other than 160, adjust the site assessment points to a base of 160. Example: if the Site Assessment maximum is 200 points, and alternative Site "A" is rated 180 points:

$$\frac{\text{Total points assigned Site A}}{\text{Maximum points possible}} = \frac{180}{200} \times 160 = 144 \text{ points for Site “A.”}$$

Site Assessment Scoring for the Twelve Factors Used in FPPA

The Site Assessment criteria used in the Farmland Protection Policy Act (FPPA) rule are designed to assess important factors other than the agricultural value of the land when determining which alternative sites should receive the highest level of protection from conversion to non agricultural uses.

Twelve factors are used for Site Assessment and ten factors for corridor-type sites. Each factor is listed in an outline form, without detailed definitions or guidelines to follow in the rating process. The purpose of this document is to expand the definitions of use of each of the twelve Site Assessment factors so that all persons can have a clear understanding as to what each factor is intended to evaluate and how points are assigned for given conditions.

In each of the 12 factors a number rating system is used to determine which sites deserve the most protection from conversion to non-farm uses. The higher the number value given to a proposed site, the more protection it will receive. The maximum scores are 10, 15 and 20 points, depending upon the relative importance of each particular question. If a question significantly relates to why a parcel of land should not be converted, the question has a maximum possible protection value of 20, whereas a question which does not have such a significant impact upon whether a site would be converted, would have fewer maximum points possible, for example 10.

The following guidelines should be used in rating the twelve Site Assessment criteria:

1. How much land is in non-urban use within a radius of 1.0 mile from where the project is intended?

More than 90 percent:	15 points
90-20 percent:	14 to 1 points
Less than 20 percent:	0 points

This factor is designed to evaluate the extent to which the area within one mile of the proposed site is non-urban area. For purposes of this rule, "non-urban" should include:

- Agricultural land (crop-fruit trees, nuts, oilseed)
- Range land
- Forest land
- Golf Courses
- Non paved parks and recreational areas
- Mining sites
- Farm Storage
- Lakes, ponds and other water bodies
- Rural roads, and through roads without houses or buildings
- Open space
- Wetlands
- Fish production
- Pasture or hayland

Urban uses include:

- Houses (other than farm houses)
- Apartment buildings
- Commercial buildings
- Industrial buildings
- Paved recreational areas (i.e. tennis courts)
- Streets in areas with 30 structures per 40 acres
- Gas stations

- Equipment, supply stores
- Off-farm storage
- Processing plants
- Shopping malls
- Utilities/Services
- Medical buildings

In rating this factor, an area one-mile from the outer edge of the proposed site should be outlined on a current photo; the areas that are urban should be outlined. For rural houses and other buildings with unknown sizes, use 1 and 1/3 acres per structure. For roads with houses on only one side, use one half of road for urban and one half for non-urban.

The purpose of this rating process is to insure that the most valuable and viable farmlands are protected from development projects sponsored by the Federal Government. With this goal in mind, factor S1 suggests that the more agricultural lands surrounding the parcel boundary in question, the more protection from development this site should receive. Accordingly, a site with a large quantity of non-urban land surrounding it will receive a greater
number of points for protection from development. Thus, where more than 90 percent of the area around the proposed site (do not include the proposed site in this assessment) is non-urban, assign 15 points. Where 20 percent or less is
non-urban, assign 0 points. Where the area lies between 20 and 90 percent non-urban, assign appropriate points from 14 to 1, as noted below.

Percent Non-Urban Land within 1 mile	**Points**
90 percent or greater	15
85 to 89 percent	14
80 to 84 percent	13
75 to 79 percent	12
70 to 74 percent	11
65 to 69 percent	10
60 to 64 percent	9
55 to 59 percent	8
50 to 54 percent	7
45 to 49 percent	6
40 to 44 percent	5
35 to 39 percent	4
30 to 24 percent	3
25 to 29 percent	2
21 to 24 percent	1
20 percent or less	0

2. How much of the perimeter of the site borders on land in non-urban use?

More than 90 percent:	l0 points
90 to 20 percent:	9 to 1 point(s)
Less than 20 percent:	0 points

This factor is designed to evaluate the extent to which the land adjacent to the proposed site is non-urban use. Where factor #1 evaluates the general location of the proposed site, this factor evaluates the immediate perimeter of the site. The definition of urban and non-urban uses in factor #1 should be used for this factor.

In rating the second factor, measure the perimeter of the site that is in non-urban and urban use. Where more than 90 percent of the perimeter is in non-urban use, score this factor 10 points. Where less than 20 percent, assign 0 points. If a road is next to the perimeter, class the area according to the use on the other side of the road for that area. Use 1 and 1/3 acre per structure if not otherwise known. Where 20 to 90 percent of the perimeter is non-urban, assign points as noted below:

Percentage of Perimeter Bordering Land	Points
90 percent or greater	10
82 to 89 percent	9
74 to 81 percent	8
65 to 73 percent	7
58 to 65 percent	6
50 to 57 percent	5
42 to 49 percent	4
34 to 41 percent	3
27 to 33 percent	2
21 to 26 percent	1
20 percent or Less	0

3. How much of the site has been farmed (managed for a scheduled harvest or timber activity) more than five of the last ten years?

More than 90 percent:	20 points
90 to 20 percent:	19 to 1 point(s)
Less than 20 percent:	0 points

This factor is designed to evaluate the extent to which the proposed conversion site has been used or managed for agricultural purposes in the past 10 years.

Land is being farmed when it is used or managed for food or fiber, to include timber products, fruit, nuts, grapes, grain, forage, oil seed, fish and meat, poultry and dairy products.

Land that has been left to grow up to native vegetation without management or harvest will be considered as abandoned and therefore not farmed. The proposed conversion site should be evaluated and rated according to the percent, of the site farmed.

If more than 90 percent of the site has been farmed 5 of the last 10 years score the site as follows:

Percentage of Site Farmed	Points
90 percent or greater	20
86 to 89 percent	19
82 to 85 percent	18
78 to 81 percent	17
74 to 77 percent	16
70 to 73 percent	15
66 to 69 percent	14
62 to 65 percent	13
58 to 61 percent	12
54 to 57 percent	11
50 to 53 percent	10
46 to 49 percent	9
42 to 45 percent	8
38 to 41 percent	7
35 to 37 percent	6
32 to 34 percent	5
29 to 31 percent	4
26 to 28 percent	3

23 to 25 percent	2
20 to 22 percent percent or Less	1
Less than 20 percent	0

4. Is the site subject to state or unit of local government policies or programs to protect farmland or covered by private programs to protect farmland?

Site is protected:	20 points
Site is not protected:	0 points

This factor is designed to evaluate the extent to which state and local government and private programs have made efforts to protect this site from conversion.

State and local policies and programs to protect farmland include:

State Policies and Programs to Protect Farmland

1. Tax Relief:

A. Differential Assessment: Agricultural lands are taxed on their agricultural use value, rather than at market value. As a result, farmers pay fewer taxes on their land, which helps keep them in business, and therefore helps to insure that the farmland will not be converted to nonagricultural uses.

1. Preferential Assessment for Property Tax: Landowners with parcels of land used for agriculture are given the privilege of differential assessment.

2. Deferred Taxation for Property Tax: Landowners are deterred from converting their land to nonfarm uses, because if they do so, they must pay back taxes at market value.

3. Restrictive Agreement for Property Tax: Landowners who want to receive Differential Assessment must agree to keep their land in - eligible use.

B. Income Tax Credits

Circuit Breaker Tax Credits: Authorize an eligible owner of farmland to apply some or all of the property taxes on his or her farmland and farm structures as a tax credit against the owner's state income tax.

C. Estate and Inheritance Tax Benefits

Farm Use Valuation for Death Tax: Exemption of state tax liability to eligible farm estates.

2. "Right to farm" laws:

Prohibits local governments from enacting laws which will place restrictions upon normally accepted farming practices, for example, the generation of noise, odor or dust.

3. Agricultural Districting:

Wherein farmers voluntarily organize districts of agricultural land to be legally recognized geographic areas. These farmers receive benefits, such as protection from annexation, in exchange for keeping land within the district for a given number of years.

4. Land Use Controls: Agricultural Zoning.

Types of Agricultural Zoning Ordinances include:

A. Exclusive: In which the agricultural zone is restricted to only farm-related dwellings, with, for example, a minimum of 40 acres per dwelling unit.

B. Non-Exclusive: In which non-farm dwellings are allowed, but the density remains low, such as 20 acres per dwelling unit.

Additional Zoning techniques include:

A. Slidinq Scale: This method looks at zoning according to the total size of the parcel owned. For example, the number of dwelling units per a given number of acres may change from county to county according to the existing land acreage to dwelling unit ratio of surrounding parcels of land within the specific area.

B. Point System or Numerical Approach: Approaches land use permits on a case by case basis.

   LESA: The LESA system (Land Evaluation-Site Assessment) is used as a tool to help assess options for land use on an evaluation of productivity weighed against commitment to urban development.

C. Conditional Use: Based upon the evaluation on a case by case basis by the Board of Zoning Adjustment. Also may include the method of using special land use permits.

5. Development Rights:

   A. Purchase of Development Rights (PDR): Where development rights are purchased by Government action.

      Buffer Zoning Districts: Buffer Zoning Districts are an example of land purchased by Government action. This land is included in zoning ordinances in order to preserve and protect agricultural lands from non-farm land uses encroaching upon them.

   B. Transfer of Development Rights (TDR): Development rights are transferable for use in other locations designated as receiving areas. TDR is considered a locally based action (not state), because it requires a voluntary decision on the part of the individual landowners.

6. Governor’s Executive Order: Policy made by the Governor, stating the importance of agriculture, and the preservation of agricultural lands. The Governor orders the state agencies to avoid the unnecessary conversion of important farmland to nonagricultural uses.

7. Voluntary State Programs:

   A. California's Program of Restrictive Agreements and Differential Assessments: The California Land Conservation Act of 1965, commonly known as the Williamson Act, allows cities, counties and individual landowners to form agricultural preserves and enter into contracts for 10 or more years to insure that these parcels of land remain strictly for agricultural use. Since 1972 the Act has extended eligibility to recreational and open space lands such as scenic highway corridors, salt ponds and wildlife preserves. These contractually restricted lands may be taxed differentially for their real value. One hundred-acre districts constitute the minimum land size eligible.

      Suggestion: An improved version of the Act would state that if the land is converted after the contract expires, the landowner must pay the difference in the taxes between market value for the land and the agricultural tax value which he or she had been paying under the Act. This measure would help to insure that farmland would not be converted after the 10 year period ends.

B. Maryland Agricultural Land Preservation Program: Agricultural landowners within agricultural districts have the opportunity to sell their development rights to the Maryland Land Preservation Foundation under the agreement that these landowners will not subdivide or develop their land for an initial period of five years. After five years the landowner may terminate the agreement with one year notice.

   As is stated above under the California Williamson Act, the landowner should pay the back taxes on the property if he or she decides to convert the land after the contract expires, in order to discourage such conversions.

C. Wisconsin Income Tax Incentive Program: The Wisconsin Farmland Preservation Program of December 1977 encourages local jurisdictions in Wisconsin to adopt agricultural preservation plans or exclusive agricultural district zoning ordinances in exchange for credit against state income tax and exemption from special utility assessment. Eligible candidates include local governments and landowners with at least 35 acres of land per dwelling unit in agricultural use and gross farm profits of at least $6.000 per year, or $18,000 over three years.

8. Mandatory State Programs:

   A. The Environmental Control Act in the state of Vermont was adopted in 1970 by the Vermont State Legislature. The Act established an environmental board with 9 members (appointed by the Governor) to implement a planning process and a permit system to screen most subdivisions and development proposals according to specific criteria stated in the law. The planning process consists of an interim and a final Land Capability and Development Plan, the latter of which acts as a policy plan to control development. The policies are written in order to:

      - prevent air and water pollution;
      - protect scenic or natural beauty, historic sites and rare and irreplaceable natural areas; and
      - consider the impacts of growth and reduction of development on areas of primary agricultural soils.

   B. The California State Coastal Commission: In 1976 the Coastal Act was passed to establish a permanent Coastal Commission with permit and planning authority The purpose of the Coastal Commission was and is to protect the sensitive coastal zone environment and its resources, while accommodating the social and economic needs of the state. The Commission has the power to regulate development in the coastal zones by issuing permits on a case by case basis until local agencies can develop their own coastal plans, which must be certified by the Coastal Commission.

   C. Hawaii's Program of State Zoning: In 1961, the Hawaii State Legislature established Act 187, the Land Use Law, to protect the farmland and the welfare of the local people of Hawaii by planning to avoid “unnecessary urbanization”. The Law made all state lands into four districts: agricultural, conservation, rural and urban. The Governor appointed members to a State Land Use Commission, whose duties were to uphold the Law and form the boundaries of the four districts. In addition to state zoning, the Land Use Law introduced a program of Differential Assessment, wherein agricultural landowners paid taxes on their land for its agricultural use value, rather than its market value.

   D. The Oregon Land Use Act of 1973: This act established the Land Conservation and Development Commission (LCDC) to provide statewide planning goals and guidelines.

Under this Act, Oregon cities and counties are each required to draw up a comprehensive plan, consistent with statewide planning goals. Agricultural land preservation is high on the list of state goals to be followed locally.

If the proposed site is subject to or has used one or more of the above farmland protection programs or policies, score the site 20 points. If none of the above policies or programs apply to this site, score 0 points.

5. How close is the site to an urban built-up area?

The site is 2 miles or more from an urban built-up area	15 points
The site is more than 1 mile but less than 2 miles from an urban built-up area	10 points
The site is less than 1 mile from, but is not adjacent to an urban built-up area	5 points
The site is adjacent to an urban built-up area	0 points

This factor is designed to evaluate the extent to which the proposed site is located next to an existing urban area. The urban built-up area must be 2500 population. The measurement from the built-up area should be made from the point at which the density is 30 structures per 40 acres and with no open or non-urban land existing between the major built-up areas and this point. Suburbs adjacent to cities or urban built-up areas should be considered as part of that urban area.

For greater accuracy, use the following chart to determine how much protection the site should receive according to its distance from an urban area. See chart below:

Distance From Perimeter of Site to Urban Area	Points
More than 10,560 feet	15
9,860 to 10,559 feet	14
9,160 to 9,859 feet	13
8,460 to 9,159 feet	12
7,760 to 8,459 feet	11
7,060 to 7,759 feet	10
6,360 to 7,059 feet	9
5,660 to 6,359 feet	8
4,960 to 5,659 feet	7
4,260 to 4,959 feet	6
3,560 to 4,259 feet	5
2,860 to 3,559 feet	4
2,160 to 2,859 feet	3
1,460 to 2,159 feet	2
760 to 1,459 feet	1
Less than 760 feet (adjacent)	0

6. How close is the site to water lines, sewer lines and/or other local facilities and services whose capacities and design would promote nonagricultural use?

None of the services exist nearer than 3 miles from the site	15 points
Some of the services exist more than one but less than 3 miles from the site	10 points
All of the services exist within 1/2 mile of the site	0 points

This question determines how much infrastructure (water, sewer, etc.) is in place which could facilitate nonagricultural development. The fewer facilities in place, the more difficult it is to develop an area. Thus, if a proposed site is further away from these services (more than 3 miles distance away), the site should be awarded the highest number of points (15). As the distance of the parcel of land to services decreases, the number of points awarded declines as well. So, when the site is equal to or further than 1 mile but less than 3 miles away from services, it should be given 10 points. Accordingly, if this distance is 1/2 mile to less than 1 mile, award 5 points; and if the distance from land to services is less than 1/2 mile, award 0 points.

Distance to public facilities should be measured from the perimeter of the parcel in question to the nearest site(s) where necessary facilities are located. If there is more than one distance (i.e. from site to water and from site to sewer), use the average distance (add all distances and then divide by the number of different distances to get the average).

Facilities which could promote nonagricultural use include:

- Water lines
- Sewer lines
- Power lines
- Gas lines
- Circulation (roads)
- Fire and police protection
- Schools

7. Is the farm unit(s) containing the site (before the project) as large as the average-size farming unit in the county? (Average farm sizes in each county are available from the NRCS field offices in each state. Data are from the latest available Census of Agriculture, Acreage of Farm Units in Operation with $1,000 or more in sales.)

As large or larger:	10 points
Below average: Deduct 1 point for each 5 percent below the average, down to 0 points if 50 percent or more is below average	9 to 0 points

This factor is designed to determine how much protection the site should receive, according to its size in relation to the average size of farming units within the county. The larger the parcel of land, the more agricultural use value the land possesses, and vice versa. Thus, if the farm unit is as large or larger than the county average, it receives the maximum number of points (10). The smaller the parcel of land compared to the county average, the fewer number of points given. Please see below:

Parcel Size in Relation to Average County Size	**Points**
Same size or larger than average (l00 percent)	10
95 percent of average	9
90 percent of average	8
85 percent of average	7
80 percent of average	6
75 percent of average	5
70 percent of average	4
65 percent of average	3
60 percent of average	2
55 percent of average	1
50 percent or below county average	0

State and local Natural Resources Conservation Service offices will have the average farm size information, provided by the latest available Census of Agriculture data

8. If this site is chosen for the project, how much of the remaining land on the farm will become non-farmable because of interference with land patterns?

Acreage equal to more than 25 percent of acres directly converted by the project	10 points
Acreage equal to between 25 and 5 percent of the acres directly converted by the project	9 to 1 point(s)
Acreage equal to less than 5 percent of the acres directly converted by the project	0 points

This factor tackles the question of how the proposed development will affect the rest of the land on the farm The site which deserves the most protection from conversion will receive the greatest number of points, and vice versa. For example, if the project is small, such as an extension on a house, the rest of the agricultural land would remain farmable, and thus a lower number of points is given to the site. Whereas if a large-scale highway is planned, a greater portion of the land (not including the site) will become non-farmable, since access to the farmland will be blocked; and thus, the site should receive the highest number of points (10) as protection from conversion

Conversion uses of the Site Which Would Make the Rest of the Land Non-Farmable by Interfering with Land Patterns

Conversions which make the rest of the property nonfarmable include any development which blocks accessibility to the rest of the site Examples are highways, railroads, dams or development along the front of a site restricting access to the rest of the property.

The point scoring is as follows:

Amount of Land Not Including the Site Which Will Become Non-Farmable	Points
25 percent or greater	10
23 - 24 percent	9
21 - 22 percent	8
19 - 20 percent	7
17 - 18 percent	6
15 - 16 percent	5
13 - 14 percent	4
11 - 12 percent	3
9 - 11 percent	2
6 - 8 percent	1
5 percent or less	0

9. Does the site have available adequate supply of farm support services and markets, i.e., farm suppliers, equipment dealers, processing and storage facilities and farmer's markets?

All required services are available	5 points
Some required services are available	4 to 1 point(s)
No required services are available	0 points

This factor is used to assess whether there are adequate support facilities, activities and industry to keep the farming business in business. The more support facilities available to the agricultural landowner, the more feasible it is for him or her to stay in production. In addition, agricultural support facilities are compatible with farmland. This fact is important, because some land uses are not compatible; for example, development next to farmland cam be dangerous to the welfare of the agricultural land, as a result of pressure from the neighbors who often do not appreciate the noise, smells and dust intrinsic to farmland. Thus, when all required agricultural support services are available, the maximum number of points (5) are awarded. When some services are available, 4 to 1 point(s) are awarded; and consequently, when no services are available, no points are given. See below:

Percent of Services Available	**Points**
100 percent	5
75 to 99 percent	4
50 to 74 percent	3
25 to 49 percent	2
1 to 24 percent	1
No services	0

10. Does the site have substantial and well-maintained on farm investments such as barns, other storage buildings, fruit trees and vines, field terraces, drainage, irrigation, waterways, or other soil and water conservation measures?

High amount of on-farm investment	20 points
Moderate amount of non-farm investment	19 to 1 point(s)
No on-farm investments	0 points

This factor assesses the quantity of agricultural facilities in place on the proposed site. If a significant agricultural infrastructure exists, the site should continue to be used for farming, and thus the parcel will receive the highest amount of points towards protection from conversion or development. If there is little on farm investment, the site will receive comparatively less protection. See-below:

Amount of On-farm Investment	**Points**
As much or more than necessary to maintain production (100 percent)	20
95 to 99 percent	19
90 to 94 percent	18
85 to 89 percent	17
80 to 84 percent	16
75 to 79 percent	15
70 to 74 percent	14
65 to 69 percent	13
60 to 64 percent	12
55 to 59 percent	11
50 to 54 percent	10
45 to 49 percent	9
40 to 44 percent	8
35 to 39 percent	7
30 to 34 percent	6
25 to 29 percent	5
20 to 24 percent	4
15 to 19 percent	3
10 to 14 percent	2
5 to 9 percent	1
0 to 4 percent	0

11. Would the project at this site, by converting farmland to nonagricultural use, reduce the support for farm support services so as to jeopardize the continued existence of these support services and thus, the viability of the farms remaining in the area?

Substantial reduction in demand for support services if the site is converted	10 points
Some reduction in demand for support services if the site is converted	9 to 1 point(s)
No significant reduction in demand for support services if the site is converted	0 points

This factor determines whether there are other agriculturally related activities, businesses or jobs dependent upon the working of the pre-converted site in order for the others to remain in production. The more people and farming activities relying upon this land, the more protection it should receive from conversion. Thus, if a substantial reduction in demand for support services were to occur as a result of conversions, the proposed site would receive a high score of 10; some reduction in demand would receive 9 to 1 point(s), and no significant reduction in demand would receive no points.

Specific points are outlined as follows:

Amount of Reduction in Support Services if Site is Converted to Nonagricultural Use	Points
Substantial reduction (100 percent)	10
90 to 99 percent	9
80 to 89 percent	8
70 to 79 percent	7
60 to 69 percent	6
50 to 59 percent	5
40 to 49 percent	4
30 to 39 percent	3
20 to 29 percent	2
10 to 19 percent	1
No significant reduction (0 to 9 percent)	0

12. Is the kind and intensity of the proposed use of the site sufficiently incompatible with agriculture that it is likely to contribute to the eventual conversion of the surrounding farmland to nonagricultural use?

Proposed project is incompatible with existing agricultural use of surrounding farmland	10 points
Proposed project is tolerable of existing agricultural use of surrounding farmland	9 to 1 point(s)
Proposed project is fully compatible with existing agricultural use of surrounding farmland	0 points

Factor 12 determines whether conversion of the proposed agricultural site will eventually cause the conversion of neighboring farmland as a result of incompatibility of use of the first with the latter. The more incompatible the proposed conversion is with agriculture, the more protection this site receives from conversion. Therefor-, if the proposed conversion is incompatible with agriculture, the site receives 10 points. If the project is tolerable with agriculture, it receives 9 to 1 points; and if the proposed conversion is compatible with agriculture, it receives 0 points.

CORRIDOR - TYPE SITE ASSESSMENT CRITERIA

The following criteria are to be used for projects that have a linear or corridor - type site configuration connecting two distant points, and crossing several different tracts of land. These include utility lines, highways, railroads, stream improvements, and flood control systems. Federal agencies are to assess the suitability of each corridor-type site or design alternative for protection as farmland along with the land evaluation information.

For Water and Waste Programs, corridor analyses are not applicable for distribution or collection networks. Analyses are applicable for transmission or trunk lines where placement of the lines are flexible.

(1) How much land is in nonurban use within a radius of 1.0 mile form where the project is intended?

(2) More than 90 percent	(3) 15 points
(4) 90 to 20 percent	(5) 14 to 1 point(s).
(6) Less than 20 percent	(7) 0 points

(2) How much of the perimeter of the site borders on land in nonurban use?

(3) More than 90 percent	(4) 10 point(s)
(5) 90 to 20 percent	(6) 9 to 1 points
(7) less than 20 percent	(8) 0 points

(3) How much of the site has been farmed (managed for a scheduled harvest or timber activity) more than five of the last 10 years?

(4) More than 90 percent	(5) 20 points
(6) 90 to 20 percent	(7) 19 to 1 point(s)
(8) Less than 20 percent	(9) 0 points

(4) Is the site subject to state or unit of local government policies or programs to protect farmland or covered by private programs to protect farmland?

Site is protected	20 points
Site is not protected	0 points

(5) Is the farm unit(s) containing the site (before the project) as large as the average - size farming unit in the County? (Average farm sizes in each county are available from the NRCS field offices in each state. Data are from the latest available Census of Agriculture, Acreage of Farm Units in Operation with $1,000 or more in sales.)

As large or larger	10 points
Below average deduct 1 point for each 5 percent below the average, down to 0 points if 50 percent or more below average	9 to 0 points

(6) If the site is chosen for the project, how much of the remaining land on the farm will become non-farmable because of interference with land patterns?

Acreage equal to more than 25 percent of acres directly converted by the project	25 points
Acreage equal to between 25 and 5 percent of the acres directly convened by the project	1 to 24 point(s)
Acreage equal to less than 5 percent of the acres directly converted by the project	0 points

(7) Does the site have available adequate supply of farm support services and markets, i.e., farm suppliers, equipment dealers, processing and storage facilities and farmer's markets?

All required services are available	5 points
Some required services are available	4 to 1 point(s)
No required services are available	0 points

(8) Does the site have substantial and well-maintained on-farm investments such as barns, other storage building, fruit trees and vines, field terraces, drainage, irrigation, waterways, or other soil and water conservation measures?

High amount of on-farm investment	20 points
Moderate amount of on-farm investment	19 to 1 point(s)
No on-farm investment	0 points

(9) Would the project at this site, by converting farmland to nonagricultural use, reduce the demand for farm support services so as to jeopardize the continued existence of these support services and thus, the viability of the farms remaining in the area?

Substantial reduction in demand for support services if the site is convened	25 points
Some reduction in demand for support services if the site is convened	1 to 24 point(s)
No significant reduction in demand for support services if the site is converted	0 points

(10) Is the kind and intensity of the proposed use of the site sufficiently incompatible with agriculture that it is likely to contribute to the eventual conversion of surrounding farmland to nonagricultural use?

Proposed project is incompatible to existing agricultural use of surrounding farmland	10 points
Proposed project is tolerable to existing agricultural use of surrounding farmland	9 to 1 point(s)
Proposed project is fully compatible with existing agricultural use of surrounding farmland	0 points

Appendix N

Mussels

U.S. Army Corps of Engineers
Memphis District

US Army Corps of Engineers®
Memphis District

St. Johns Bayou Basin and New Madrid Floodway, MO

MUSSEL SURVEY

October 2010

Abstract

Qualitative mussel surveys were completed on twenty-five of the twenty-eight planned survey locations for the St. Johns Bayou Basin/New Madrid (SJNM) Floodway, Missouri project during October 2010. The surveys were conducted in order to determine whether adequate unionid mussel populations were present for long-term monitoring of potential project impacts related to the authorized SJNM project. Beginning in the spring of 2009, many of the ditches in the project area were cleaned out as part of a Natural Resources Conservation Service funded effort, including many of the ditches in which Barnhart (1998) conducted surveys. Several of these locations were subsequently surveyed by U. S. Army Corps of Engineers (USACE) personnel in 2005. Sites surveyed during the 2010 USACE effort included locations in St. Johns Bayou, St. Johns Ditch, Setback Levee Ditch (Spillway Ditch), St. James Ditch, Mud Ditch, St. John's Diversion Ditch, Wilkerson Ditch, and Ten Mile Pond Conservation Area. A total of 160 live unionid mussels representing 15 different species were collected. The most common species, in order of abundance, were: *Amblema plicata, Pyganodon grandis,* and *Lasmigona complanata.* Two species were represented by only one live individual (*Lampsilis cardium* and *Truncilla truncata).* Two species considered rare in Missouri were also collected *Arcidens confragosus* and *Anodonta suborbiculata*. Although mussel surveys were not conducted in 2010 at three locations due to site conditions, previous studies indicated that habitat at these sites did not support healthy freshwater mussel populations.

The results of the surveys conducted in 2010 indicate that the recent and ongoing ditch cleanouts have eliminated a large portion of the previously encountered freshwater mussel population in the project area ditches. The existing communities do not appear to be adequate at this time for establishing baseline conditions from which to assess potential impacts from the SJNM project. Studies currently underway in other locations on the recovery of mussel populations after channel cleanouts may help determine when the appropriate level of recovery that would allow for meaningful data collection can be expected in these ditches.

Introduction

The SJNM Floodway Project was originally authorized for construction by the Water Resources Development Act of 1986 (PL 99-662), Section 401(a). This authorization was based on the Report of the Chief of Engineers, dated 4 January 1983, which was part of the Phase I General Design Memorandum documents prepared in response to Section 101(a) of the Water Resources Development Act of 1976 (PL 94-587). An Environmental Impact Statement (EIS) for SJNM is currently being developed.

Several construction items are authorized in the St. Johns Bayou Basin. These items consist of channel enlargements in the lower 4.5 miles of St. Johns Bayou, 8.1 miles of Setback Levee Ditch, and 7.1 miles of St. James Ditch. Freshwater mussel surveys were conducted in 2010 to update previous surveys (Barnhart, 1998; USACE 2005); determine potential relocation sites, and aid in determining appropriate methods for implementing long-term monitoring of the freshwater mussel resource. Previous coordination between USACE and federal and state resource agencies resulted in the recommendation that a portion of the mussel population in Setback Levee Ditch be relocated, and that long-term monitoring be conducted over a 10-year time period to measure recolonization following channel alteration.

Objectives

The objective of this monitoring effort was to determine the status of existing mussel populations within the SJNM Project Area. The approach utilized generally followed that used by Barnhart (1998) and previous surveys conducted by USACE (2005). Catch-per-unit effort (CPUE) data was collected during these qualitative sampling efforts and were used to compare previous mussel populations with current conditions.

Previous Project Area Surveys

Barnhart (1998) surveyed 28 sites within the SJNM project area. The major ditches in the project area were surveyed at intervals of approximately 2-miles. A total of 988 live unionids representing 23 species were collected during this effort. Overall CPUE was 14.17 live individuals per man-hour. The most abundant species, in order of abundance, were: *Amblema plicata*, *Quadrula quadrula*, and *Pyganodon grandis.* The highest species diversity and greatest abundance were found in the lower portions of St. James Ditch and in Setback Levee Ditch. Barnhart's survey found the SJNM project area supported a diverse and fairly abundant unionid fauna, typical of drainage canals in the Mississippi lowlands of Missouri and Arkansas.

In June 2005, fourteen locations were surveyed in the SJNM project area by USACE personnel. The objectives of this study were to conduct pre-construction surveys of Mud Ditch, where four 10-foot by 10-foot gated box culverts were to be constructed; determine if previous surveys results (Barnhart, 1998) were still valid with current conditions; identify potential relocation sites, and to aid in determining methods for implementing long-term monitoring of the freshwater mussel resource. Previous coordination with resource agencies recommended relocating a portion of the unionid mussel population of Setback Levee Ditch and conducting long-term monitoring over a 10-year period to measure recolonization success following project related channel alteration. A total of 802 live unionids representing 13 species were collected.

Overall CPUE was 37.53 live individuals per man-hour. The most abundant species in the 2005 effort, in order of abundance, were: *A. plicata*, *Q. quadrula*, and *L. complanata*. As was the case during Barnhart's surveys, the highest species diversity and greatest abundance were found in the lower portions of St. James Ditch and in Setback Levee Ditch. This survey confirmed that the SJNM still supported a diverse and abundant freshwater mussel population.

Methods

Qualitative mussel surveys were conducted in 2010 by wading and grubbing to locate freshwater mussels. Although a minimum of one person-hour search time at each specific site was initially proposed, discussions with Missouri Department of Conservation and U.S. Fish and Wildlife Service malacologists determined less than one person-hour at each location would suffice if potential mussel habitat was poor. Therefore timed searches were conducted that continued at least 15 minutes after the last new species was collected. Catch-per-unit effort data was collected and used to compare previous mussel populations with current conditions. The general habitat (depth, current, turbidity) at each site was noted and the substrate of the surveyed reach was recorded. All available microhabitats within the survey site were searched. Live mussels encountered were identified, enumerated, and placed back into the substrate from where they were collected. Fresh dead shells were identified and recorded. Nomenclature followed Turgeon *et al*. (1998). GPS coordinates were recorded. Survey results are archived in the Memphis District's GIS database. A copy of the field datasheets can be found in the Appendix.

Results

A total of 25 sites were searched over a 23.05 man-hour period (Figure 1, Table 1). The average search time per site was 0.94 man-hours. A total of 160 live unionid mussels representing 15 different species were collected (Table 1). Overall CPUE was 6.94 individual mussels.

Beginning in the spring of 2009 and continuing through the present time (January 2010), the local levee district has dredged many project area channels to authorized levels. This activity was funded through the U.S. Department of Agriculture, Natural Resources Conservation Service. Thirteen of the surveyed locations have been dredged to date as part of the current effort. Of the remaining nine non-impacted locations, two are scheduled to be dredged with the current funding while the clean-out schedule for the remaining seven locations is unclear.

At seven locations no mussels were encountered (five locations in the St. Johns Bayou Basin and two locations in the New Madrid Floodway). Sixteen sites had five or less mussels collected.

Habitat and depths varied throughout the survey sites. Table 2 provides information on the general habitat type and substrate observed.

Discussion

The project area supported a relatively diverse, abundant, and stable freshwater mussel population typical of a deltaic stream systems prior to this recent channel cleanout. These cleanouts may explain the low number of live mussels collected in 2010 when compared to previous unionid mussel surveys within the project area. Whether this decrease in population is permanent or merely temporary is unknown at this time, but if past sampling events are the measure, the mussel population has the ability rebound back to similar, pre-disturbance levels, given a sufficient amount of time.

Overall mussel numbers were reduced, but similar species were collected in comparison to previous studies in the project area (Tables 3-6). In areas that have not been dredged, the mussel population trended in a similar fashion to previous studies and overall abundance was higher than non-dredged locations.

In one area that had been recently dredged (Site 17), a strip of mussels were observed on the bank opposite of where the cleanout occurred. This indicates areas of mussels may exist where the heavy equipment “missed” any existing mussel beds.

Channel maintenance history indicated portions of the ditches surveyed in 1998 had been previously cleaned out between 1984 and 1988. Mussel populations appeared to have re-colonized from this impact by 1998. A similar trend in abundance and densities were observed in the 2005 surveys. These data indicate the mussel populations in SJNM should be able to re-colonize within 10-15 years, with additional perturbations either slowing down or halting growth of the population. Recolonization would also be dependent on availability of suitable habitat and hosts.

Authorized project features, *i.e.* channel widening may further affect the mussel population by decreasing water levels in the main ditches of the project area surveyed. Overall habitat would be potentially decreased, in a similar fashion to the recent ditch cleanouts, but the population would be expected to return to pre-disturbance levels.

The seven locations were no mussels were collected were: four in the upper St. James Ditch, two in lower Mud Ditch, and one location in St. Johns Ditch. The St. James Ditch locations were in areas with low to no flow, impeded by beaver dams or minimal water levels. Similar results were obtained in the previous Barnhart survey in the upper three locations. The two locations in lower Mud Ditch were most likely attributable to poor habitat as the 2010 data closely paralleled the 1998 data. The St. Johns location may be associated with the recent channel work or poor habitat, however only four mussels were collected in 1998 suggesting this may be habitat related. These data would indicate that habitat is the controlling force in the project area.

Table 1. Results of October 2010 surveys[1,2].

Site Number	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19	20	21	22	23	24	25	26
	SJoD	SJoD	SJoD	SJoD	SJoB	WD	SJaD	WD	SJDD	MD	MD	MD	SJoD	TMP	SLD	SLD	SLD	SLD	SLD	SLD	SJaD	SJaD	SJaD	SJaD	SJaD
Species																									
Anodonta suborbiculata				4							1					1	3		2						
Amblema plicata	1	3													5	20	7	6	3	3					
Arcidens confragosus								1								3	1		2	2	2				
Lampsilis cardium							1																		
Lampsilis teres							6		1							2				2					
Lasmigona complanata	1							2								1	2	4	3		3				
Leptodea fragilis					1	1										2	1								
Potamilus purpuratus		1					2		1							3		1			1				
Pyganodon grandis							7	3						5					2		3				
Quadrula pustulosa						1									1						1				
Quadrula quadrula						1		3	1		1					1	6	2							
Tritogonia verrucosa	1	1											2						1						
Truncilla truncata																1									
Uniomerus tetralasmus							3																		
Strophitus undulatus							1																		
Total Search Time (min)	50	80	60	58	50	60	72	80	66	32	46	32	60	84	60	80	64	74	60	60	72	30	32	20	30
Total Search Time (hr)	0.83	1.33	1.00	0.97	0.83	1.00	1.20	1.33	1.10	0.53	0.77	0.53	1.00	1.40	1.00	1.33	1.07	1.23	1.00	1.00	1.20	0.50	0.53	0.33	0.50
Number of Live Individuals	3	5	0	4	1	3	20	9	3	0	2	0	2	5	6	34	20	13	13	7	10	0	0	0	0
CPUE (Individuals/hr)	3.60	3.75	0.00	4.14	1.20	3.00	16.67	6.75	2.73	0.00	2.61	0.00	2.00	3.57	6.00	25.50	18.75	10.54	13.00	7.00	8.33	0.00	0.00	0.00	0.00
Total Number of Species	3	3	0	1	1	3	6	4	3	0	2	0	1	1	2	9	6	4	6	3	5	0	0	0	0

[1] Stream abbreviations used: St. Johns Bayou (SJoB), St. Johns Ditch (SJoD), St. Johns Diversion Ditch (SJDD), Mud Ditch (MD), Setback Levee Ditch (SLD), St. James Ditch (SJaD), Ten Mile Pond Ditch (TMD), Wilkerson Ditch (WD). Basin Abbreviations used: St. Johns Bayou Basin (SJBB) and New Madrid Floodway (NMF).
[2]Site 14 was not sampled in 2010.

Table 2. 2010 Freshwater Mussel Survey, Habitat Conditions.[1]

Site	General Habitat	Approx. Avg. Depth	Approx. Width	Substrate	Recent Dredging
01	Some woody debris, low turbidity	0.5 m	30 m	Sand	Yes
02	Unstable sand, some woody debris, low turbidity	0.5 m	30 m	Sand	Yes
03	Unstable sand, low turbidity	0.5 m	30 m	Sand over clay	Yes
04	Unstable sand, low turbidity	0.5 m	30 m	Sand over clay	Yes
05	Lots of woody debris, trash, turbid	0.5 m	35 m	Clay, gravel, sand	No
06	Low current, woody debris, high turbidity	0.5 m	35 m	Silt, sand	Yes
07	Few aquatic plants, woody debris, low turbidity, trash dump to east	0.5 m	15 m	Silt, some sand	No
08	Aquatic vegetation, high turbidity	0.5 m	20 m	Silt	Yes
09	Lots of woody debris, unconsolidated silt, turbid	0.75 m	20 m	Unconsolidated silt, woody debris	No
10	Very turbid, aquatic vegetation, woody debris, immediately downstream of on-going cleanout	0.5 m	7 m	Clay, unconsolidated silt	No*
11	Very turbid, some woody debris, downstream of on-going cleanout	0.5 m	7 m	Clay, unconsolidated silt	No*
12	Turbid, some woody debris	0.5 m	15 m	Unconsolidated silt	Yes
13	Turbid, some woody debris	0.5 m	30 m	Unstable sand	Yes
15	Turbid, some woody debris	1 m	15 m	Clay with fairly stable silt and limited unconsolidated silt pockets	Yes
16	Low turbidity, highly degraded site	0.2 m	15 m	Unstable sand, some silt and sand	Yes
17	Low turbidity, cattle grazing on east side	0.3 m	25 m	Sand with some silt	Yes
18	Low turbidity, cattle grazing on east side	0.3 m	25 m	Sand with some silt	Yes
19	Low turbidity, some woody debris	0.7 m	25 m	Sand, hard clay	Yes
20	Low turbidity, some woody debris	0.5 m	25 m	Silt with some clay	Yes

Site	General Habitat	Approx. Avg. Depth	Approx. Width	Substrate	Recent Dredging
21	Low turbidity, some aquatic vegetation	0.4 m	25 m	Unstable sand with some silt	Yes
22	Silt, turbid, Hydrilla and algae, downstream of beaver dam	0.1 m	3 m	Silt	No
23	Aquatic plants, algae, low turbidity	0.2 m	11 m	Very thick layer of silt with particles of vegetation	No
24	Sand covered with algae, aquatic vegetation, minnows abundant	0.04 m	1 m	Sand covered with algae	No
25	Woody Debris, some vegetation, downstream of beaver dam, low turbidity	10 cm		Silt, organic	No
26	Woody Debris, low turbidity	30 cm	15 m	Sand with algae on top	No

[1]Site 14 not sampled during 2010.

Table 3. Comparison of results of mussel surveys over time at each site.

	Barnhart 1998		MVM 2005[1]		MVM 2010	
Stations	No. of Individuals	No. of species	No. of Individuals	No. of species	No. of Individuals	No. of species
1	14	7			3	3
2	34	5			5	3
3	4	2			0	0
4	3	3			4	1
5	0	0			1	1
6	34	4			3	3
7	86	6			20	6
8	8	5			9	4
9	18	7			3	3
10	3	2			0	0
11	1	1			2	2
12	11	3			0	0
13	27	9	24	8	2	1
14	9	4			-	-
15	7	1			5	1
16	30	7	31	4	6	2
17	236	10	92	9	34	9
18	37	11			20	6
19	26	6	35	10	13	4
20	23	7			13	6
21	81	4	101	9	7	3
22	170	10	209	7	10	5
23	96	11	31	5	0	0
24	1	1			0	0
25	2	1			0	0
26	0	0			0	0
27	18	5			-	-
28	9	4			-	-
Totals	988	23 spp.	523	13 spp.	160	15 spp.

[1]Of the fourteen sites surveyed in 2005, only seven locations occurred in the vicinity of previous studies, the remaining seven locations focused on potential re-location areas. Numbers presented in this table reflect only those seven similar locations. Sites 14, 27, and 28 were not surveyed in 2010 due to site conditions.

Table 4. Number of live mussels collected by species during the 2010 survey effort.

Species	Total Live Mussels	Percent of Total	Number of Sites	Percent of Sites
Amblema plicata	48	30.00	8	32
Pyganodon grandis	20	12.50	5	20
Lasmigona complanata	16	10.00	7	28
Quadrula quadrula	15	9.38	7	28
Anodonta suborbiculata	11	6.88	5	20
Arcidens confragosus	11	6.88	6	24
Lampsilis teres	11	6.88	4	16
Potamilus purpuratus	9	5.63	6	24
Leptodea fragilis	5	3.13	4	16
Tritogonia verrucosa	5	3.13	4	16
Quadrula pustulosa	3	1.88	3	12
Uniomerus tetralasmus	3	1.88	1	4
Lampsilis cardium	1	0.63	1	4
Truncilla truncata	1	0.63	1	4
Strophitus undulatus	1	0.63	1	4

Table 5. Number of live mussels collected by species during the 2005 sampling effort.

Species	Total Live Mussels	Percent of Total	Number of Sites	Percent of Sites
Amblema plicata	535	66.71	10	71.4
Quadrula quadrula	79	9.85	9	64.3
Lasmigona complanata	50	6.23	9	64.3
Quadrula pustulosa	32	3.99	7	50.0
Tritogonia verrucosa	26	3.24	5	35.7
Lampsilis teres	24	2.99	7	50.0
Pyganodon grandis	18	2.24	7	50.0
Potamilus purpuratus	17	2.12	8	57.1
Arcidens confragosus	10	1.25	6	42.9
Leptodea fragilis	5	0.62	3	21.4
Fusconaia flava	3	0.37	2	14.3
Truncilla truncata	2	0.25	2	14.3
Lampsilis cardium	1	0.12	1	7.1

Table 6. Number of live mussels collected by species by Barhart during the 1998 sampling effort.

Species	Total Live Mussels	Percent of Total	Number of Sites	Percent of Sites
Amblema plicata	528	53.44	15	53.6
Quadrula quadrula	90	9.11	15	53.6
Pyganodon grandis	84	8.50	17	60.7
Quadrula pustulosa	74	7.49	11	39.3
Lasmigona complanata	47	4.76	15	53.6
Potamilus purpuratus	28	2.83	14	50.0
Leptodea fragilis	24	2.43	10	35.7
Lampsilis teres	23	2.33	4	14.3
Arcidens confragosus	16	1.62	5	17.9
Utterbackia imbecillis	15	1.52	2	7.1
Quadrula nodulata	14	1.42	4	14.3
Tritogonia verrucosa	12	1.21	5	17.9
Potamilus ohiensis	7	0.71	1	3.6
Lampsilis cardium	5	0.51	5	17.9
Toxolasma parvus	5	0.51	1	3.6
Anodonta suborbiculata	3	0.30	3	10.7
Obliquaria reflexa	3	0.30	2	7.1
Toxolasma texasensis	3	0.30	1	3.6
Truncilla truncata	3	0.30	2	7.1
Fusconaia flava	1	0.10	1	3.6
Ligumia subrostrata	1	0.10	1	3.6
Potamilus alatus	1	0.10	1	3.6
Uniomerus tetralasmus	1	0.10	1	3.6

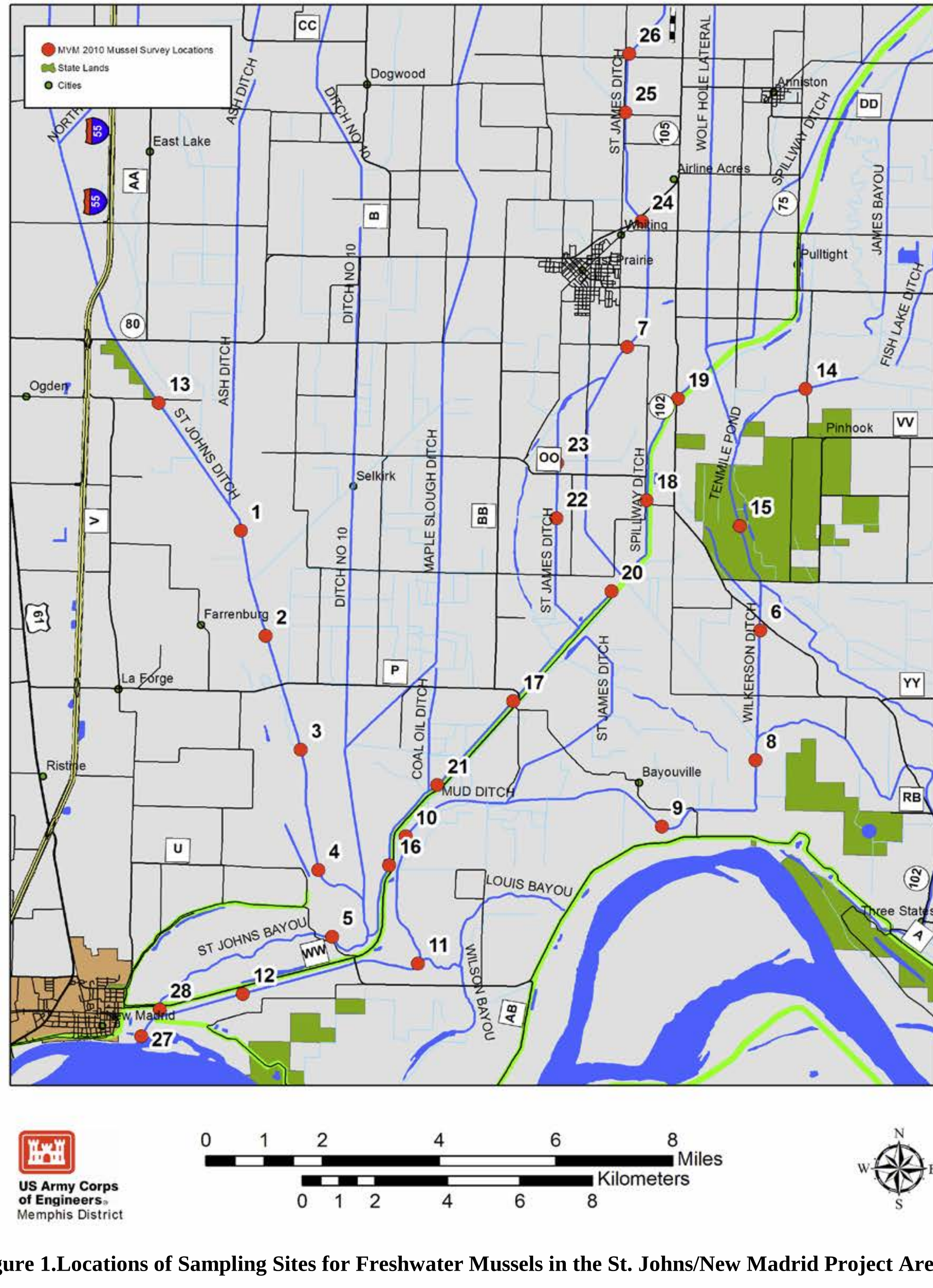

Figure 1.Locations of Sampling Sites for Freshwater Mussels in the St. Johns/New Madrid Project Area.

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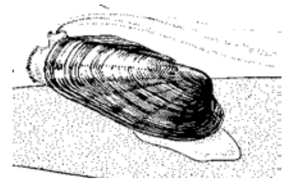
Appendix



FIELD DATA SHEET

Project Name: Date:

1. Survey Site: Reach (m):
2. Surveyors: Search Time:
4. GPS Coordinates:
5. Survey Methods Used (circle all applied): Relic Hand Rake Snorkel Scuba
6. River Stage:

Species	Common Name	Present (√)	Number identified Relic	Live	Total Live
AC – Arkansas Commercial E – Endangered SC – AR tracked sp. of concern					
Actinonaias ligamentina	Mucket				
Alasmidonta marginata	Elktoe				
Amblema plicata (AC)	Threeridge				
Anodonta suborbiculata (SC)	Flat floater				
Arcidens confragosus	Rock pocketbook				
Corbicula fluminea	Asian clam				
Cyclonaias tuberculata	Purple wartyback				
Cyprogenia aberti (SC)	Western Fanshell				
Dreissena polymorpha	Zebra mussel				
Ellipsaria lineolata	Butterfly				
Elliptio dilatata	Spike				
Fusconaia ebena (AC)	Ebonyshell				
Fusconaia flava	Wabash pigtoe				
Lampsilis abrupta (E) (SC)	Pink mucket				
Lampsilis cardium	Plain pocketbook				
Lampsilis hydiana	Louisiana fatmucket				
Lampsilis teres	Yellow sandshell				
Lasmigona complanata	White heelsplitter				
Leptodea fragilis	Fragile papershell				
Ligumia recta	Black sandshell				
Ligumia subrostrata	Pondmussel				
Megalonaias nervosa (AC)	Washboard				
Obliquaria reflexa	Threehorn wartyback				
Obovaria olivaria	Hickorynut				
Plectomerus dombeyanus	Bankclimber				
Pleurobema rubrum (SC)	Pyramid pigtoe				
Pleurobema sintoxia	Round pigtoe				
Potamilus alatus (SC)	Pink heelsplitter				
Potamilus capax (E) (SC)	Fat pocketbook				
Potamilus ohiensis	Pink papershell				
Potamilus purpuratus	Bleufer				
Pyganodon grandis	Giant floater				
Quadrula cylindrica (SC)	Rabbitsfoot				
Quadrula metanevra	Monkeyface				
Quadrula nodulata	Wartyback				
Quadrula pustulosa	Pimpleback				
Quadrula quadrula (AC)	Mapleleaf				
Toxolasma sp. (lividus-purple:SC)	Lilliput sp				
Tritogonia verrucosa	Pistolgrip				
Truncilla truncata	Deertoe				
Uniomerus tetralasmus	Pondhorn				
Utterbackia imbecillis	Paper pondshell				
TOTAL:					

Measurements

A. plicata (w)	*M. nervosa (w)*	*Q. quadrula (w)*	*F. ebena (w)*	*P. capax (l&w))*		

Comments:

- Photos:
- General Habitat (depth, current, turbidity, etc.):
- Substrate:
- Other:

MAP OF SITE:

Report:

A Survey of Unionid Mussels in the St. John's Basin and the New Madrid Floodway

March 1, 1998

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Abstract

A survey of unionid mussels was conducted in the St. John's Basin and the New Madrid Floodway in the summer of 1997. The survey was undertaken in order to describe the unionid fauna of reaches that will be impacted by the anticipated East Prairie Phase of the St. John's Bayou-New Madrid Floodway Project. The study reaches were located in St. John's Bayou, St. John's Ditch, Setback Levee Ditch (=Spillway Ditch), St. James Ditch, Mud Ditch (=East Bayou Ditch), St. John's Diversion Ditch, Wilkerson Ditch, and the 10-Mile Pond Wildlife Area. A total of 28 sites were searched spaced at intervals of approximately 2 miles. Total catch was 998 live unionids representing 23 species. Overall catch per unit effort (CPUE) was 15.3 individual mussels per man-hour. The seven most abundant species, in order of abundance, were the threeridge, mapleleaf, giant floater, pimpleback, white heelsplitter, bleufer, and fragile papershell. Each of these species was found at more than half of the sites that were examined. Four species that are considered rare in Missouri were found. These species are the rock pocketbook (*Arcidens confragosus*), flat floater (*Anodonta suborbiculata*), wartyback (*Quadrula nodulata*), and Texas lilliput (*Toxolasma texasensis*). The highest species diversity and greatest abundance of individuals was found in the lower portions of St. James Ditch and in the Setback Levee (Spillway) Ditch. Overall, the study area supports a diverse and fairly abundant unionid fauna, consisting of at least 24 species. This fauna appears to be typical of the drainage canals of the Mississippi lowlands in Missouri and Arkansas.

Presently, the outlet of the New Madrid Floodway is the only directly-connected tributary of the Mississippi River in the entire Missouri Bootheel. This gap would be closed by the proposed project. A gated outlet would be constructed for the New Madrid Floodway to limit flooding from the Mississippi, and auxillary pumping stations would be installed for both outlets to move water out of the basins when the gates are closed.

The study reaches in the St. John's Bayou drainage basin were located in St. John's Bayou, St. John's Ditch, Setback Levee Ditch (also known as "Spillway Ditch"), and St. James Ditch. Study reaches in the New Madrid Floodway basin were located in Mud Ditch (also known as "East Bayou Ditch"), St. John's Diversion Ditch, Wilkerson Ditch, and the 10-Mile Pond Wildlife Area (Appendix 1, Figures 2,3).

Study Methods

All sites were surveyed between July 16 and September 20, 1997. Water depths during the searches were generally less than 1-meter. Study sites were located at approximately 2-mile intervals in most reaches. Some sites were accessible from roadways, but most were reached by canoe. Each site was visited by a crew of 2-4 workers. Qualitative sampling was carried out by visual searches when the substrate was visible, or more often by sweeping the substrate by hand. In areas that were relatively free of debris, a 1.5-meter length of PVC pipe was pushed sideways along the surface of the substrate. Contact with shells anywhere along the length of the pipe can be felt, and the effective search area is thereby considerably increased. Mean search time was 2.25 man-hours per site. Mussels were placed in mesh bags as they were collected during the timed search. Afterward, specimens were examined, identified to species, and measured. Most individuals were then returned to the substrate in proper orientation.

Qualitative sampling is efficient in determining relative abundance and species richness (Vaughn et al. 1997, Obermeyer 1998). We also performed quantitative sampling at ten of the 28 study sites in order to ascertain the practicality of measuring population densities. Following the timed search, from 16 to 28 quadrats were searched in the area immediately downstream of the qualitative sampling area. Each quadrat was

1ae

0.25-m^2 in area. The quadrats were placed randomly at an average density of 1 quadrat per 25 m^2 (i.e. average 1% coverage). The relatively uniform and fine-grained substrates in many Bootheel ditches permit the recovery of small (young) individuals, which are difficult to locate in gravel and cobble substrates (Roberts et al., 1997). Quadrat sampling was carried out using a sampling device similar in design to a Surbur sampler. This device consisted of a sieve box, open on one end, attached to a 0.25 $meter^2$ (side length 0.5 meter) quadrat frame. The sieve box and quadrat frame were made from 1-inch steel tubing, and the sieve box was lined with 0.25-inch mesh galvanized hardware cloth. In use, the sampler was laid on the substrate with the quadrat frame positioned upstream. Substrate was excavated by hand to a depth of several inches within the frame and pushed downstream into the sieve box. When the excavation was complete the frame was tilted up and shaken to flush the sediments through the screened sides.

In each ditch, at least one individual of each species collected was retained as a voucher specimen. Voucher specimens were fixed in buffered formalin and preserved in 70 percent ethanol. Specimens were labeled with species identification, the date and the locality of collection. Voucher specimens were deposited with the Missouri Department of Conservation, Columbia, Missouri.

Results

Qualitative sampling: A total of 28 sites were searched (Table 1). The average search time per site was 2.24 man-hours. Total search time was 62.8 man-hours. In total, 998 live unionids were recovered, representing 23 species. Overall catch per unit effort (CPUE) in the qualitative sampling was 15.3 individual mussels per man-hour. These figures are based on live individuals. Consideration of dead shells added somewhat to the species counts at some sites (Table 1). Live individuals greatly outnumbered dead shells. Therefore, it appears that shells probably degrade or are buried rather quickly in this habitat. For this reason, the presence of dead shells in good condition is probably a reliable indicator of the presence of live individuals of that species at the site.

In total, live individuals of 23 species were recovered. One other species (*Lampsilis siliquoidea*) was found only as recently dead shells. Percent of catch and percent of sites where present were tabulated for each species (Table 2, Figures 4, 5). *Amblema plicata* was particularly common, occurring at 57% of the sites examined and accounting for 53% of the total catch. This species was particularly abundant in the St. James Ditch and the Setback Levee Ditch, where it exceeded 60% of the catch (Figure 7). In descending order, the seven most numerically abundant species were *Amblema plicata*, *Quadrula quadrula*, *Pyganodon grandis*, *Quadrula pustulosa*, *Lasmigona complanata*, *Potamilus purpuratus*, and *Leptodea fragilis* (Table 2, Figure 4). These same seven species were all widespead as well as abundant within the survey area. Each was found at more than half of the sites that were examined (Table 2, Figure 5). Four species that are considered rare in Missouri were found. These species are *Arcidens confragosus*, *Anodonta suborbiculata*, *Quadrula nodulata*, and *Toxolasma texasensis*.

Comparisons of study basins and reaches: The mean number of species found per site and the mean CPUE were determined for each of the four major ditch reaches sampled (Table 3). Species composition within these reaches was tabulated (Figures 6, 7, 8, 9). The difference between overall and local species composition in these reaches was also calculated (Figures 10, 11, 12, 13).

St. John's Bayou and St. John's Ditch: The eight sites sampled in St. John's Bayou and St. John's Ditch were relatively unproductive, with mean CPUE of 6.3 mussels/hour and a mean of 4.9 species/site. Species composition in these reaches contrasted somewhat with the overall survey results. *Quadrula pustulosa* and *Potamilus purpuratus* were more common, while *Amblema plicata* was relatively less common (Figures 6, 10). Substrate in these ditches was generally fine, dark sand, often with woody debris mixed in, and appeared to be relatively loose and unstable. Channel width was 30-40 meters and water depth was typically 60-80 cm.

Setback Levee Ditch: The six sites surveyed in the Setback Levee (Spillway) Ditch were the richest of the four major reaches, with mean CPUE of 27.7 mussels/hour and a mean of 7.8 species/site. Compared to the overall survey, *Amblema plicata* was relatively abundant (Figures 7, 11). Particularly productive sites were numbers 17, 18, and 21. These sites were wooded with mature trees on the west bank, while the east bank (the levee side) was devoid of woody vegetation. Most mussels at these sites were found within 1-2 meters of the wooded bank. These areas had clean, fine sand substrate that was relatively compact and stable. The ditch was relatively narrow (12-20 meters wide), and water depth of the sampled areas was shallow, generally 25-45 cm.

St. James Ditch: The St. James Ditch was the narrowest ditch surveyed. Channel width was only 6-11 m. Depth was variable and was often less than 20 cm in the upper reaches. Probably for this reason, both CPUE and species/site dropped substantially moving from the downstream to the upstream sites (Figure 14). The lower sites were quite productive with CPUE up to 56.7 and up to 11 species per site. Average CPUE in St. James Ditch was 22.4 mussels/hour and mean species/site was 6.2. Species composition was similar to that of the overall survey (Figures 8, 12). Substrate at the lower, productive sites (22, 23, 7) consisted of fine silt overlaying sand. Trees were present at most sites, but most of the woody vegetation at site 24 had recently been cut. This area did not appear to have been dredged for some time.

New Madrid Floodway ditches: The eight study sites within the New Madrid Floodway Basin (Mud Ditch, St. John's Diversion Ditch, Wilkerson Ditch, 10-Mile Pond) yielded 91 individual mussels of ten species. Overall CPUE for these sites was relatively low at 5.8 mussels/hour. The mean number of species/site was 5.1. For comparison between basins, the 20 study sites within the St. John's Basin yielded 897 individuals of 22 species, CPUE of 19.2 and species/site of 5.4. Species composition of the New Madrid ditches differed somewhat from the overall survey results. *Amblema plicata* was less abundant, while *Quadrula quadrula, Pyganodon grandis,Leptodea fragils,* and *Quadrula nodulata* comprised a larger proportion of the catch (Figures 9, 13). No species were found in the New Madrid basin that were not also found in the St. John's basin. On the other hand, 13 species found in the St. John's basin were not recovered from the New Madrid basin. Channel widths at sites in the New Madrid basin ranged from 14-25 m and depths of sampled areas generally ranged from 25-80 cm. Downstream sites in Mud Ditch had soft mud substrate, while more upstream sites in St. John's Diversion Ditch and Wilkerson Ditch had sand substrate. Sites in the Ten-Mile Pond area had mud substrate. Substrate was generally loose throughout.

Quantitative sampling. Overall, only 25 individual mussels were recovered in 204 quadrat samples, indicating an overall population density in the sampled area of 0.49 individuals per m^2. Mussel densities in the survey area were too low to be accurately estimated by the number of quadrat samples employed. The overall population density in the study area is probably still lower, because the sites chosen for quadrat sampling were generally those with higher densities. These results are consistent with our subjective impression that mussel populations within the ditches are generally more dispersed than is typical of natural waterways. In natural rivers and streams, unionid distribution is highly clumped, and the population concentrations are referred to as 'beds'. Natural streams are highly heterogeneous environments, and mussel beds appear to form in localized areas of suitable habitat. In the ditches, we did not note concentrations that would warrant the term 'bed'. Presumably, the relative uniformity of physical habitat and substrate results in a less clumped distribution of individuals.

Size and age distributions. The ages of individual *Amblema plicata*, estimated by counting annuli, were correlated with shell length, although there was considerable variation in size within age classes (Figure 17). The youngest individuals recovered were in their second year of growth and were less than 20 mm long. Individuals below 100 mm shell length generally appeared to be less than 10 years in age. It was difficult to accurately count annuli in older individuals. Growth slows in older individuals, so that annuli are more closely spaced, and erosion of shells of older individuals also tends to obscure the growth lines.

The size distribution of *Amblema plicata* in the Setback Levee Ditch was markedly bimodal. Relatively few individuals were recovered in the range of 80-120 mm in length (Figure 18). Size distributions varied among sites, but this cohort was relatively rare at all sites (Figure 19). In contrast, the size distribution of *Amblema* in the St. James Ditch was unimodal, with most individuals in the range of 60-100 mm in length (Figure 20).

Discussion

Most of the over 300 North American species of unionid mussels have declined greatly in recent decades and many species are in danger of extinction (Williams et al. 1992). The man-made waterways that drain the agricultural lands in southeast Missouri and northeast Arkansas are significant unionid habitat. The combination of moderate depth and current speed, stable flows, sandy substrates, substantial groundwater flow, and, presumably, abundant fish hosts found in these ditches provides good conditions for certain unionid species. Relative to natural rivers of similar size, mussel populations in these ditches appear to be relatively diverse, abundant, and rather uniformly distributed.

Two other surveys of mussels in ditch habitats are available for comparison with the present study. Ahlstedt and Jenkinson sampled 31 sites in man-made ditches and modified St. Francis River tributaries in east-central and northeast Arkansas. These sites were studied as part of an extensive survey of the St. Francis River and its tributaries (Ahlstedt and Jenkinson 1987, Jenkinson and Ahlstedt 1987, Ahlstedt and Jenkinson 1991). Roberts et al. (1997) surveyed 67 sites on ditches in Dunklin and Pemiscott Counties in southeastern Missouri. Both of these surveys were undertaken primarily to investigate the presence and abundance of the federally listed fat pocketbook mussel, *Potamilus capax*. The combined data from the present and previous surveys are consistent and show that at least 30 species of unionids presently inhabit the lowland drainage ditches (Figures 15, 16). Overall, *Amblema plicata* is the most abundant ditch species, followed by *Potamilus purpuratus, Pyganodon grandis, Quadrula quadrula, Quadrula nodulata, Leptodea fragilis,* and *Quadrula pustulosa* (Figure 15). The most frequently encountered species are *Potamilus purpuratus, Pyganodon grandis, Leptodea fragilis, Amblema plicata, Quadrula quadrula, Lasmigona complanata,* and *Lampsilis teres* (Figure 16).

Federally endangered species: The federally endangered fat pocketbook mussel, *Potamilus capax*, is found in ditch tributaries of the St. Francis River at least as far north as Dunklin County, Missouri (Roberts et al. 1997, Ahlstedt and Jenkinson 1991). Fat pocketbooks were not found in the present survey. However, a previous environmental survey reported fat pocketbooks to be present in Fish Lake Ditch at Hwy 80, just northeast of the Ten Mile Pond area (ESEI 1978). No other unionid species or sites were reported in that study. Without voucher specimens available for examination, it is impossible to determine whether this is a valid record, and we are inclined to discount it. Untrained observers readily confuse several other relatively inflated species of unionids with *Potamilus capax*, including female *Lampsilis cardium* and *Potamilus purpuratus* (personal observations).

State-listed rare species: Four Missouri state-rare species were found in this survey. These are the rock pocketbook (*Arcidens confragosus*), flat floater (*Anodonta suborbiculata*), wartyback (*Quadrula nodulata*), and Texas lilliput (*Toxolasma texasensis*). Missouri is well within the historic range of the rock pocketbook, flat floater and wartyback, whereas the Texas lilliput is probably on the edge of its range in the study area. The ditches of the Bootheel lowlands appear to provide the most important habitat for all of these species within the state of Missouri.

The rock pocketbook (*Arcidens confragosus*) was historically distributed in the Mississippi River and major tributaries from Minnesota to the Gulf of Mexico, as well as several Gulf river systems from Texas to Alabama (Clarke 1981). In Missouri, it has previously been found sporadically in the lower Meramec River, St. Francis River, and the Osage River (Oesch 1984) and more commonly in the ditches of the Missouri Bootheel (Jenkinson and Ahlstedt 1987; Roberts et al. 1997). This species generally inhabits medium to large rivers in pools and areas of reduced flow in mud and sand (Baker 1928, Cummings and Mayer 1992). In the lowlands, *Arcidens confragosus* appears to be associated with stable but silty substrate (Jenkinson and Ahlstedt 1987, present study). Suspected host fishes include freshwater drum, gizzard shad, rock bass, white crappie, and American eel (Surber 1913, Wilson 1916 cited by Watters 1994). However, this list is based upon limited observations of attached glochidia on wild-caught fish and these host relationships need to be confirmed by lab study. According to Utterback (1915) the rock pocketbook is bradytictic and probably gravid from September to June.

In the present survey, *Arcidens confragosus* comprised 1.62% of the total catch and was 9th in abundance of 17 ranks (Table 2, Figure 4). Other ditch surveys report abundances of 0.5% (Roberts et al. 1997) and 1.29% (Ahlstedt and Jenkinson 1991). This species was most abundant in the lower St. James Ditch at sites 22 and 23. Occasional live individuals and dead shells were also found in sites at the Setback Levee Ditch, Mud Ditch, and the 10-Mile Pond area.

The flat floater (*Anodonta suborbiculata*) occurs within the Mississippi River basin from Nebraska, Iowa, Illinois, Indiana, and Kansas, south to Louisiana (Murray and Leonard 1962, Cummings and Mayer 1992). Although the range of *A. suborbiculata* covers a large area, the distribution of the species is not continuous. Over much of its range the flat floater appears to be a relatively specialized inhabitant of the oxbow lakes and backwaters of large rivers (Utterback 1915, Johnson 1980, Oesch 1984). Flat floaters typically can be found in soft mud substrate in still or slowly flowing water (Cope 1983). In suitable habitats, flat floaters may be abundant, but habitat loss has left this species highly local in distribution and threatened over much of its range. Flat floaters in Kansas spawn in September and October and release glochidia in January and February. Many fishes appear to serve as hosts. Natural glochidial cysts were observed on gizzard shad, white crappie, bluegill, largemouth bass, golden shiners, freshwater drum, and brook silverside. Transformation of glochidia to juveniles was observed on golden shiners, warmouth, white crappie and largemouth bass (Barnhart et al. 1996). In the present survey, flat floaters comprised 0.3% of the total catch. Abundance was 15th of 17 ranks (Table 2, Figure 4). Other ditch surveys report abundances of 0.3% (Roberts et al. 1997) and 2.11% (Ahlstedt and Jenkinson 1991). Live individuals and recently dead shells were found in Mud Ditch, Ten-Mile Pond, and St. James Ditch.

The wartyback mussel (*Quadrula nodulata*) is found in the Mississippi, Illinois and Ohio rivers and the lower portions of major tributaries, where it prefers areas of sand or fine gravel (Cummings and Mayer 1992). In Missouri, this species has not generally been found far from the mainstem Mississippi, although there are isolated records from the South Grand River in Henry County, Missouri (an Osage River tributary) and several sites on the Salt River in Pike, Ralls and Monroe Counties (Oesch 1984). This species appears to be relatively abundant in the drainage canals and ditches of the lowlands in southeastern Missouri and northeastern Arkansas (Roberts et al. 1997, Jenkinson and Ahlstedt 1987). Principle component analysis of habitat associations suggest that this species may prefer relatively unstable substrates (Jenkinson and Ahlstedt 1987). The wartyback is tachytictic and is gravid with embryos or glochidia at least into mid-July (Coker et al. 1921, Roberts et al. 1997), probably releasing its glochidia in late July and early August. A few glochidia attributed to *Quadrula nodulata* were observed in natural infections on white crappie by Surber (1914) and channel catfish (Coker et al. 1921) but the natural hosts of this mussel need to be systematically investigated. One or more species of catfish appear to be the most likely hosts, based on other *Quadrula* species. The distribution of wartybacks suggests that the host may be found primarily in or close to large rivers. In the present survey, the wartyback made up 1.42% of the catch and ranked 11th in abundance of 17 ranks (Table 2, Figure 4). Other ditch surveys report abundances of 9.5% (Roberts et al. 1997) and 8.31% (Ahlstedt and Jenkinson 1991). This species occurred at three sites in the New Madrid Floodway ditches, specifically in St. John's Diversion Ditch (site 9) and Wilkerson Ditch (sites 6, 8). *Quadrula nodulata* was also found at site 17 in the Setback Levee Ditch.

The Texas lilliput mussel (*Toxolasma texasensis*) was first reported in Missouri in the last decade from the Belle Fountain Ditch drainage in Pemiscot County (Ahlstedt and Jenkinson 1987, Roberts et al, 1997). This is a southern species that finds the northern limit of its distribution in southern Illinois and Missouri (Cummings and Mayer 1992). Natural glochidia cysts of this species have been observed on warmouth and bluegill (Stern and Felder 1978). In the present study, the Texas lilliput was rare and was found at only sites 22 and 23 in the St. James Ditch. It comprised only 0.3% of the total survey catch. Other ditch surveys report abundances of 1.2% (Roberts et al. 1997) And 0.12% (Ahlstedt and Jenkinson 1991).

Fish hosts: The distribution and abundance of fishes is a major influence on the distribution and abundance of unionids, because the larval stages of unionids are obligate parasites on fishes. Most mussels are able to utilize only one or a few species of fish as host. Unionid diversity and fish diversity are strongly correlated in the Ohio River Basin, with a slope of approximately 2.2 fish species per unionid species (Watters 1992). A higher ratio of fish species to mussel species appears to characterize the present study area. Preliminary results of fish sampling indicate more than 74 fish species are present in the study area (Robert Sheehan, personal communication). Based upon Watter's results we might, therefore, expect 74/2.2= 33 species of mussels. Although the present man-made habitats in the lowlands are favorable for some mussel species, it appears likely that many others have been lost from the natural fauna.

Host specificity varies among unionids. Some species appear to utilize a single host, while others are able to transform on several host species. The host relations of most mussel species are poorly known. Many of the mussel species found in the lowland ditches are known to utilize freshwater drum as a primary or sole host for the transformation of the glochidia larvae. These include fat pocketbook (*Potamilus capax*), bleufer (*P. purpuratus*), pink papershell (*P. ohiensis*), pink heelsplitter (*P. alatus*), fragile papershell (*Leptodea fragilis*), fawnsfoot (*Truncilla donaciformis*), deertoe (*Truncilla truncata*). Others that are suspected of utilizing drum as host include the rock pocketbook (*Arcidens confragosus*). Catfishes are probable hosts of *Quadrula* species, and centrarchids such as white crappie are probable hosts of the abundant threeridge.

Mussel diversity and abundance are dependent upon a diverse and abundant fish population. The dispersal of unionids and their ability to colonize new habitats and to recolonize after local extirpation also depends upon the freedom of fish hosts to move among sites, particularly at those times when glochidia are encysted. Therefore, mussel conservation efforts must necessarily include native fish conservation efforts.

Dredging history and age distributions: The lowland drainage ditches were created by dredging and are maintained by periodic dredging. Dredging necessarily displaces and destroys a large proportion of the local mussel fauna. Because adult mussels are relatively immobile, recovery of depleted populations must take place by recruitment of juveniles from upstream or downstream mussel populations, transported by fish hosts. Hypothetically, therefore, the effects of dredging an area should be evident years later as a truncated age distribution, i.e, one lacking individuals older than the last dredging event. The time course of population recovery and the effects of dredging on subsequent recruitment might be deduced from local age distributions.

Records indicate that the most recent large-scale dredging of the Setback Levee Ditch occurred in 1988, approximately 9 years preceeding our survey (Table 4). Interestingly, the size distribution of *Amblema plicata* in this ditch is not truncated, but rather is strongly bimodal, with numbers of large, apparently old individuals (>120 mm, probably >15 years old) and of small, apparently young individuals (<80 mm, probably <10 years old), with very few individuals of intermediate age (Figure 18). Evidently, dredging did not destroy all adult individuals at most sites, since individuals that predate the dredging are still present. These older individuals tended to be concentrated along the wooded bank at sites where only one side was cleared at the time of the dredging. The presence of older mussels, missed by the dredging, and of younger mussels, recruited since the dredging, is not surprising. However, the relative rarity of the intermediate age cohort is puzzling. If this age cohort was present at the time of the dredging, it should have been spared along with the older individuals.

The relative rarity of the 80-120 mm (roughly 9-15 year old) class of *Amblema* in Setback Levee Ditch could be the result of increased recruitment following the dredging in 1988. If the survival rate of juvenile mussels improved following the dredging, this might be reflected in the strong numbers in the 60-80 mm cohort (roughly 5-8 year olds). The suggestion that dredging might enhance mussel recruitment must certainly be considered with caution, but should not be dismissed out of hand. It should be remembered that dredging in these low-gradient waterways is carried out in order to maintain uniform gradient and flow and thereby reduce siltation. These restoration of these conditions and the exposure of clean sand substrates by dredging could very well favor mussel recruitment.

It is unfortunate that essentially nothing is known of the timing of the recovery of mussel populations following dredging events in these lowland ditches. Given that dredging occurs routinely throughout the lowlands, and has for many decades, opportunities clearly exist to study the time course of population recovery and species succession following these events. Studies that would correlate local dredging history with the age structure and species composition of mussel communities could be highly instructive, and could easily and quickly be carried out. Such studies are necessary before informed decisions can be made regarding mussel conservation in this area.

Conclusions: The study area supports a diverse, abundant, and generally distributed unionid fauna which is apparently typical of the drainage canals of the Mississippi lowlands in Missouri and Arkansas. At least 24 species are present. Four Missouri state-rare species are present in the surveyed area. The highest species diversity and greatest abundance of individuals was found in the lower portions of St. James Ditch and in the Setback Levee Ditch. The presence of mature woody vegetation on banks in the Setback Levee Ditch Ditch appeared to correlate with the presence of relatively abundant and diverse unionids. Areas of obviously loose, silty and unstable substrate in the lower St. John's Bayou were depauperate of mussels, as was the upper end of the surveyed reach of the St. James Ditch. Comparison of the survey results from the two drainage basins showed that the New Madrid Floodway ditches support a subset of the species found in the St. John's basin. The size distribution of *Amblema* in the Setback Levee Ditch is bimodal, with most individuals either <80 mm (<10 years old) or >120 mm (>15 years old). This distribution suggests that recruitment of *Amblema* may have been enhanced following dredging in 1988. Further study on the effects of dredging on mussel populations is needed and could be accomplished efficiently by correlating mussel populations with dredging history in selected reaches.

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Table 1. Summary of survey results by site number. Abbreviations indicate reaches as follows: St. Johns Bayou Ditch (SJoD), St. John's Bayou (SJoB), Wilkerson Ditch (WD), St. James Ditch (SJaD), St. John's Diversion Ditch (SJDD), Mud Ditch (MD), Ten Mile Pond (TMP), Setback Levee Ditch (SLD), and the St. John's Bayou Outlet Ditch (OL).

Species	Site numbers and reaches																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	SJoD	SJoD	SJoD	SJoD	SJoB	WD	SJaD	WD	SJDD	MD	MD	MD	SJoD	TMP	TMP	SLD	SLD	SLD	SLD	SLD	SLD	SJaD	SJaD	SJaD	SJaD	SJaD	OL	OL
Anodonta suborbiculata	-	-	-	-	-	-	-	-	-	-	(2)	1	-	1	(2)	-	-	-	-	-	-	-	1(2)	-	-	-	-	-
Amblema plicata	4	8	1	1	-	-	70	-	1	-	-	-	8	-	-	12	194(3)	19(3)	10(1)	8	48(2)	141(1)	3	(1)	-	-	-	-
Arcidens confragosus	-	-	-	-	-	-	1(1)	-	-	(1)	-	-	-	-	(1)	-	-	1(1)	-	1	-	7	6	-	-	-	-	-
Fusconaia flava	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(1)	1	-	-	-	-	-	-	-	-	-	-
Lampsilis cardium	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1(1)	-	-	-	-	1	-	1(1)	-	-	-	-
Lampsilis teres	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	(1)	-	-	(1)	-	-	2(2)	15(1)	-	-	-	-	1
Lampsilis siliquoidea	-	-	-	-	-	-	(4)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(6)	-	-	-	-
Lasmigona complanata	2	-	-	-	-	2	3	1(1)	1	-	-	-	1	1(2)	-	2	1	1(1)	3	7	1	9(2)	12(1)	(1)	-	-	-	-
Leptodea fragilis	-	(2)	-	-	-	6(2)	-	2	6	(7)	(2)	1(1)	1	(2)	-	2	-	2	-	1(1)	-	1(1)	-	-	-	-	2	(1)
Ligumia subrostrata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Obliquaria reflexa	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potamilus alatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Potamilus ohiensis	-	-	-	-	-	-	-	-	-	(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	(1)
Potamilus purpuratus	1(2)	1	-	1	-	-	-	(1)	1	-	-	-	1(3)	1	-	-	2	2(1)	4(1)	3(2)	-	2	2	(2)	-	-	4	3
Pyganodon grandis	(1)	-	-	-	-	-	4(5)	2	-	(1)	1(2)	9	1	6(10)	7(2)	1(2)	1	2(1)	1	2(2)	-	2(5)	35(9)	-	2	-	4	4
Quadrula nodulata	-	-	-	-	-	7	-	2	2	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Quadrula pustulosa	4	22	3	1	-	-	-	-	5	-	-	-	3	-	-	4	5	1(1)	4(2)	-	22(1)	-	-	-	-	-	-	-
Quadrula quadrula	1(1)	2	-	-	-	19	3	1	-	2	-	-	7	(1)	-	8	24(1)	4(1)	4	1	10	3(1)	-	-	-	-	-	1
Toxolasma parvus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
Toxolasma texasensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(1)	3	-	-	-	-	-
Tritogonia verrucosa	1	1	-	-	-	-	-	-	-	-	-	-	4	-	-	-	3	3(1)	-	-	-	-	-	-	-	-	-	-
Truncilla truncata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-
Uniomerus tetralasmus	-	-	-	-	-	-	(C)	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Utterbackia imbecillis	-	-	-	-	-	-	-	-	-	(1)	(1)	-	-	-	-	-	-	-	-	-	-	2(5)	13(8)	-	-	-	-	-
Minutes search time	196	240	120	120	120	120	120	120	120	120	80	80	240	160	160	240	180	150	120	120	120	180	180	90	60	60	120	30
Number of live individuals	14	34	4	3	0	34	86	8	18	3	1	11	27	9	7	30	236	37	26	23	81	170	96	1	2	0	18	9
CPU (individuals/hour)	4.3	8.5	2.0	1.5	0.0	17.0	43.0	4.0	9.0	1.5	0.8	8.3	6.8	3.4	2.6	7.5	78.7	14.8	13.0	11.5	40.5	56.7	32.0	0.7	2.0	0.0	9.0	18.0
Number of species live	7	5	2	3	0	4	6	5	7	2	1	3	9	4	1	7	10	10	6	7	4	10	11	1	1	0	5	4
Additional species dead	1	1	0	0	0	0	2	1	0	5	4	0	0	2	2	1	1	0	1	0	0	1	0	5	0	0	0	2
Total number of species	8	6	2	3	0	4	8	6	7	7	5	3	9	6	3	8	11	10	7	7	4	11	11	6	1	0	5	6

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Table 2. Live catch summary by species. Columns show total live individuals captured, percent of total live catch by species, number of sites at which each species was found live, and percent of total sites at which each species was found live.

Species	Common name	Total live mussels	Percent of total	Number of sites	Percent of sites
Amblema plicata	threeridge	528	53.44	16	57.1
Quadrula quadrula	mapleleaf	90	9.11	16	57.1
Pyganodon grandis	giant floater	84	8.50	19	67.9
Quadrula pustulosa	pimpleback	74	7.49	11	39.3
Lasmigona complanata	white heelsplitter	47	4.76	16	57.1
Potamilus purpuratus	bleufer	28	2.83	16	57.1
Leptodea fragilis	fragile papershell	24	2.43	15	53.6
Lampsilis teres	yellow sandshell	23	2.33	6	21.4
Arcidens confragosus	rock pocketbook	16	1.62	7	25.0
Utterbackia imbecillis	paper pondshell	15	1.52	4	14.3
Quadrula nodulata	wartyback	14	1.42	4	14.3
Tritogonia verrucosa	pistolgrip	12	1.21	5	17.9
Potamilus ohiensis	pink papershell	7	0.71	3	10.7
Lampsilis cardium	plain pocketbook	5	0.51	5	17.9
Toxolasma parvus	lilliput	5	0.51	1	3.6
Anodonta suborbiculata	flat floater	3	0.30	5	17.9
Obliquaria reflexa	threehorn wartyba	3	0.30	2	7.1
Toxolasma texasensis	Texas lilliput	3	0.30	2	7.1
Truncilla truncata	deertoe	3	0.30	2	7.1
Fusconaia flava	Wabash pigtoe	1	0.10	1	3.6
Ligumia subrostrata	pond mussel	1	0.10	1	3.6
Potamilus alatus	pink heelsplitter	1	0.10	1	3.6
Uniomerus tetralasmus	pondhorn	1	0.10	2	7.1
Lampsilis siliquoidea	fat mucket	0	0.00	2	7.1

Table 3. Descriptions of qualitative searches and search results summarized by reach.

Totals and means for qualitative searches in St. John's Bayou Outlet (OL), St. John's Bayou (SJB), and St. John's Ditch (SJoD)

Reach	OL	OL	SJoB	SJoD	SJoD	SJoD	SJoD	SJoD	Means
Site numbers	27	28	5	4	3	2	1	13	
Minutes search time	120	30	120	120	120	240	196	240	148.3
Number of live individuals	18	9	0	3	4	34	14	27	13.6
CPUE (individuals/hour)	9.0	18.0	0.0	1.5	2.0	8.5	4.3	6.75	6.3
Number of species live	5	4	0	3	2	5	7	9	4.4
Additional species dead	0	2	0	0	0	1	1	0	0.5
Total number of species	5	6	0	3	2	6	8	9	4.9

Totals and means for qualitative searches in the Setback Levee Ditch (SLD)

Reach	SLD	SLD	SLD	SLD	SLD	SLD	Means
Site numbers	16	17	21	20	18	19	
Minutes search time	240	180	120	120	150	120	155.0
Number of live individuals	30	236	81	23	37	26	72.2
CPUE (individuals/hour)	7.5	78.7	40.5	11.5	14.8	13.0	27.7
Number of species live	7	10	4	7	10	6	7.3
Additional species dead	1	1	0	0	0	1	0.5
Total number of species	8	11	4	7	10	7	7.8

Totals and means for qualitative searches in the St. James Ditch (SJaD)

Reach	SJaD	SJaD	SJaD	SJaD	SJaD	SJaD	Means
Site numbers	22	23	7	24	25	26	
Minutes search time	180	180	120	90	60	60	115.0
Number of live individuals	170	96	86	1	2	0	59.2
CPUE (individuals/hour)	56.7	32.0	43.0	0.7	2.0	0.0	22.4
Number of species live	10	11	6	1	1	0	4.8
Additional species dead	1	0	2	5	0	0	1.3
Total number of species	11	11	8	6	1	0	6.2

Totals and means for sites searched in Mud Ditch (MD), St. John's Diversion Ditch (SJDD), Wilkerson Ditch (WD) and Ten Mile Pond (TMP)

Reach	MD	MD	MD	SJDD	W	W	TMP	TMP	Means
Site numbers	12	11	10	9	8	6	15	14	
Minutes search time	80	80	120	120	120	120	160	160	120.0
Number of live individuals	11	1	3	18	8	34	7	9	11.4
CPUE (individuals/hour)	8.3	0.8	1.5	9.0	4.0	17.0	2.6	3.4	5.8
Number of species live	3	1	2	7	5	4	1	4	3.4
Additional species dead	0	4	5	0	1	0	2	2	1.8
Total number of species	3	5	7	7	6	4	3	6	5.1

Table 4: Channel maintenance history. Information supplied by Kristen Palizza, USACE. Source: St. John Levee and Drainage District.

Ditch Name	Years	Reach dredged
Setback Levee Ditch	1988	Downstream from St. James Ditch
Mud Ditch	1984-1987	Most of ditch length, working downstream to upstream
St. John's Diversion Ditch	1984-1985	Most of ditch length, working downstream to upstream

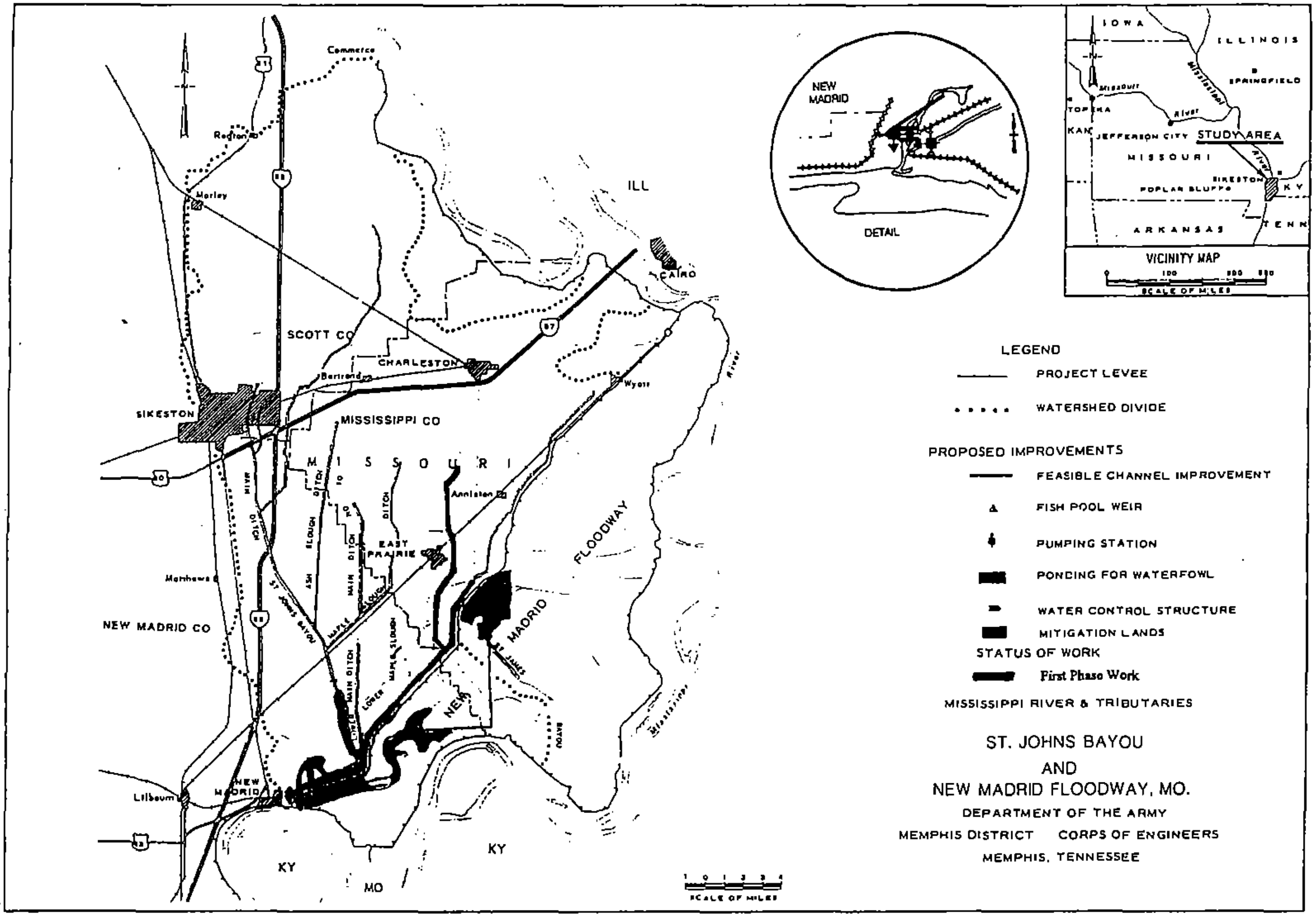
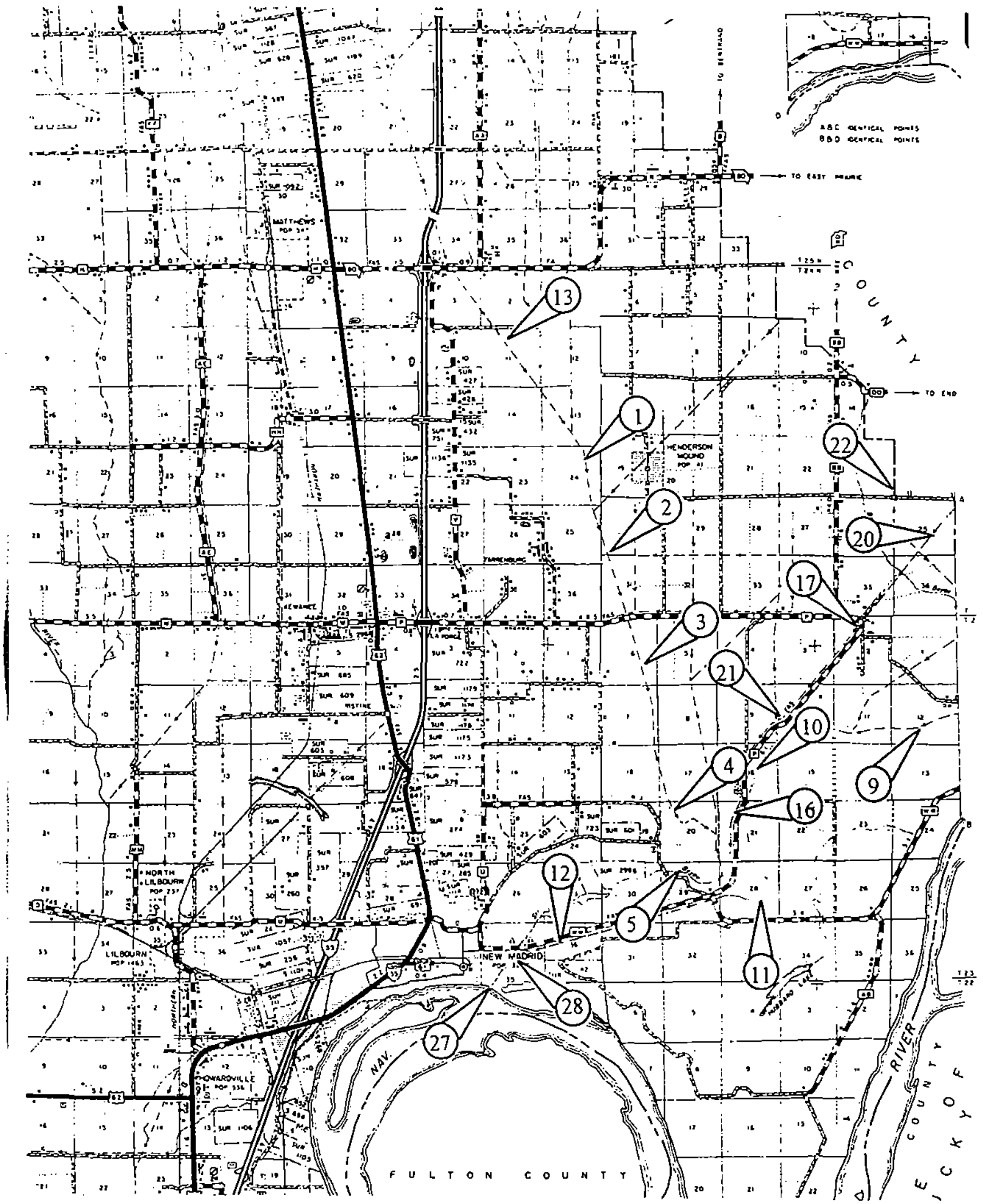


Figure 1. Study area.

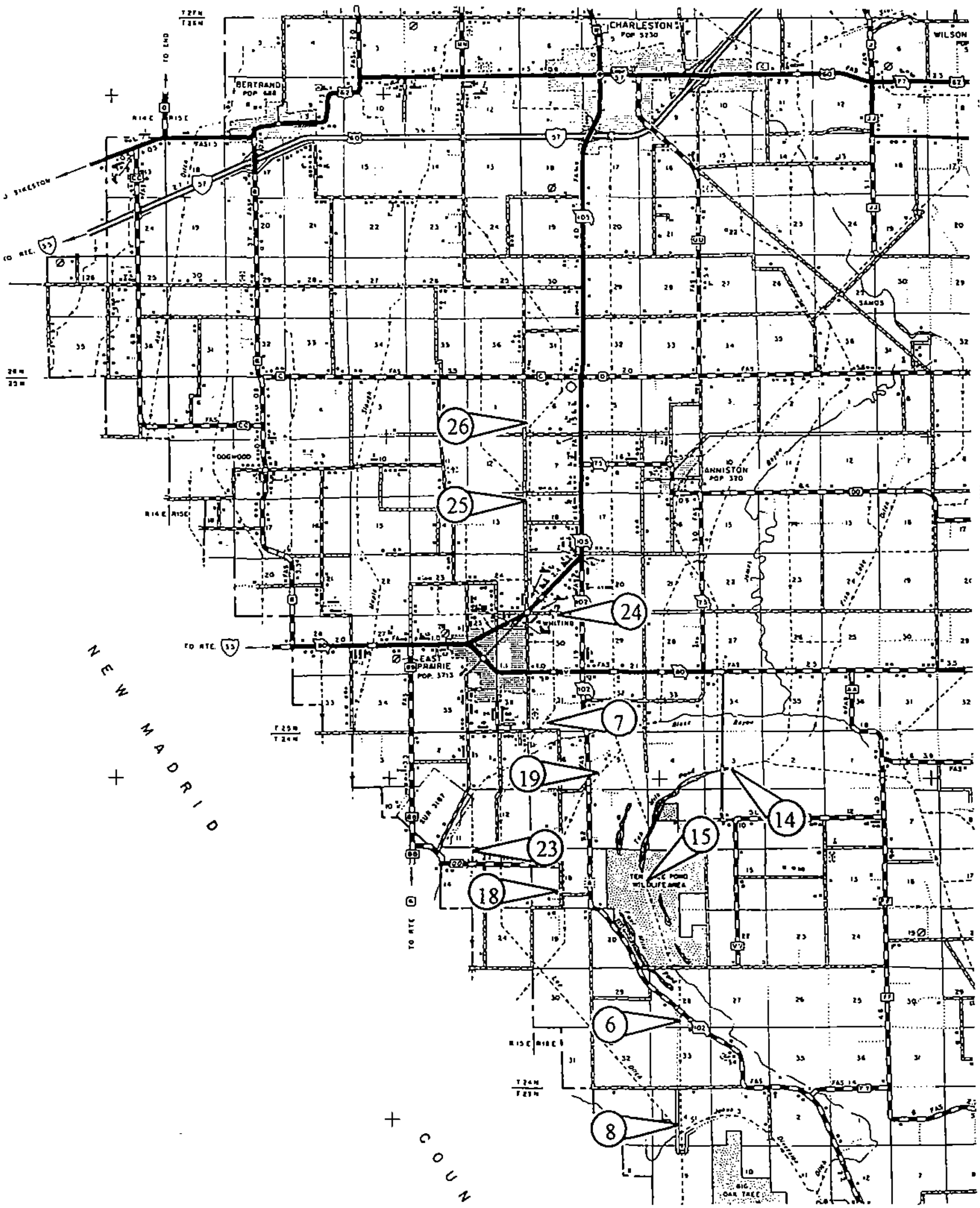
125

Figure 2. Study sites in New Madrid County, Missouri.



126

Figure 3. Study sites in Mississippi County, Missouri.



127

Figure 4. Relative species abundance in live catch.

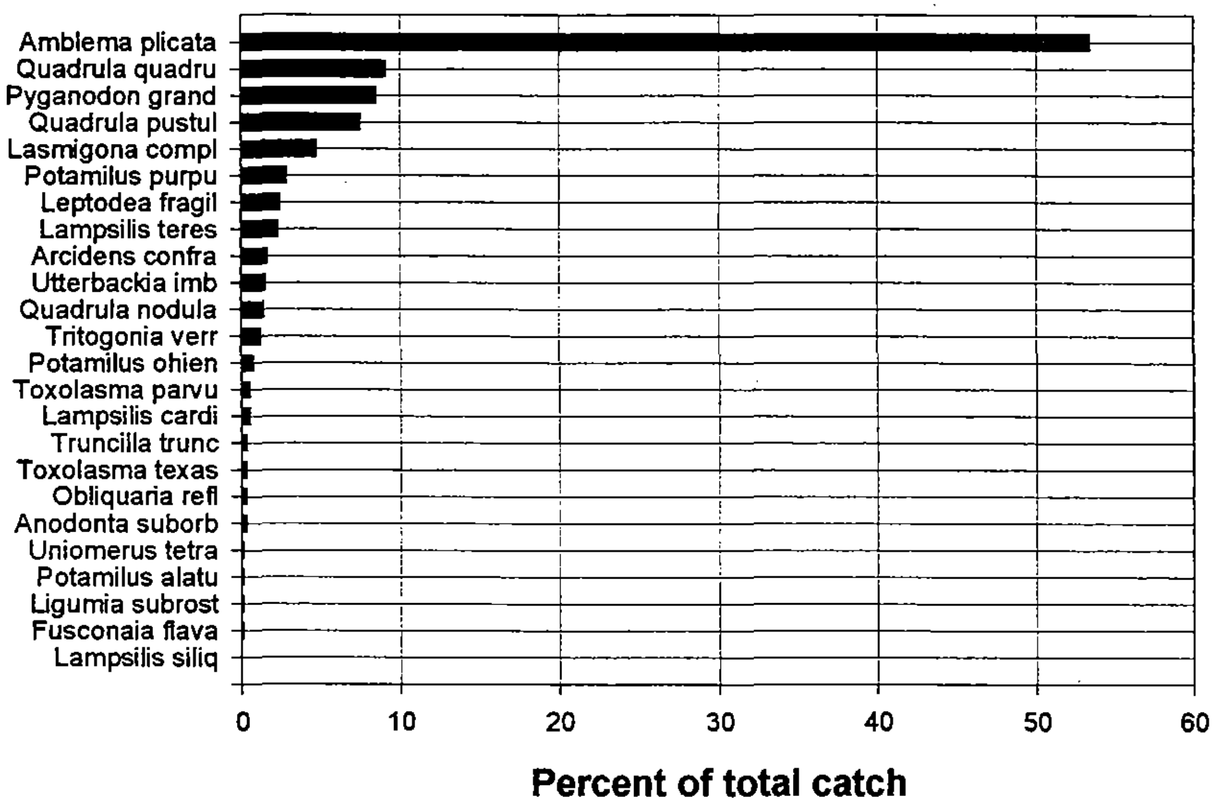


Figure 5. Percentage of sites at which each species was found live.

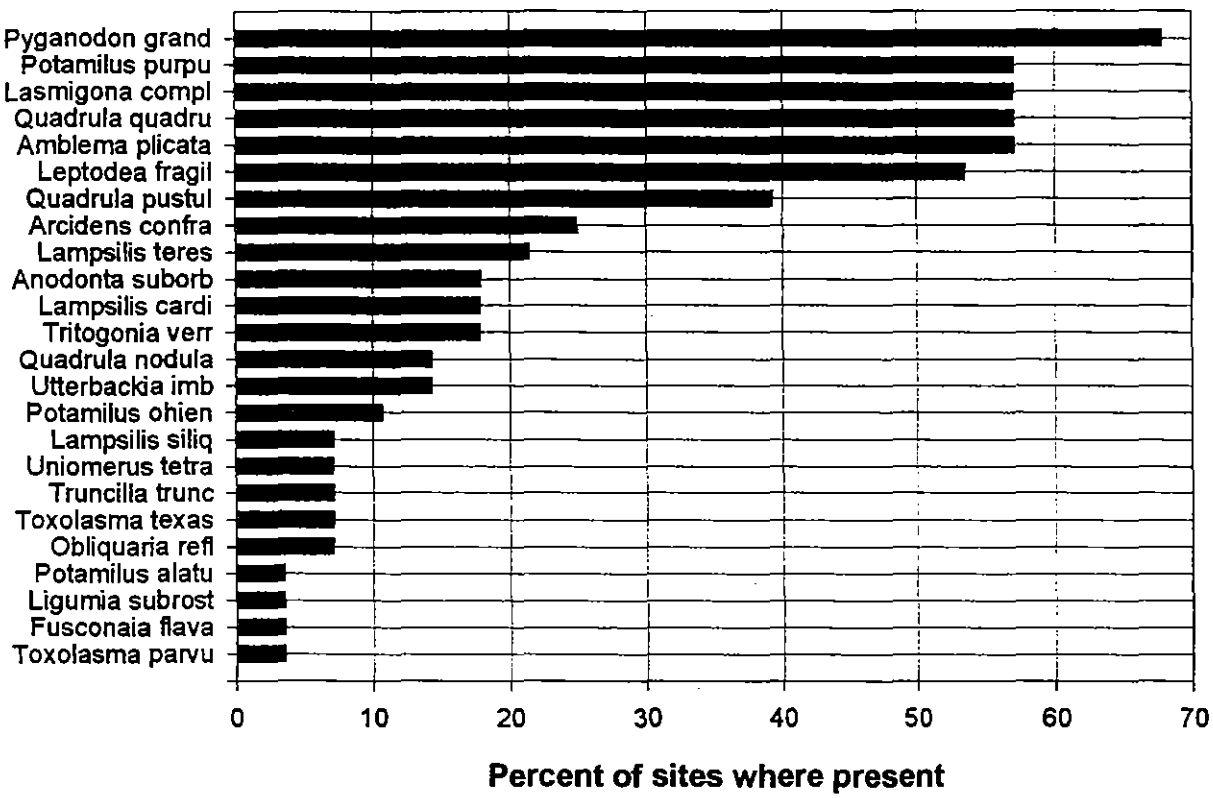


Figure 6. Relative species abundance in St. John's Ditch and St. John's Bayou.

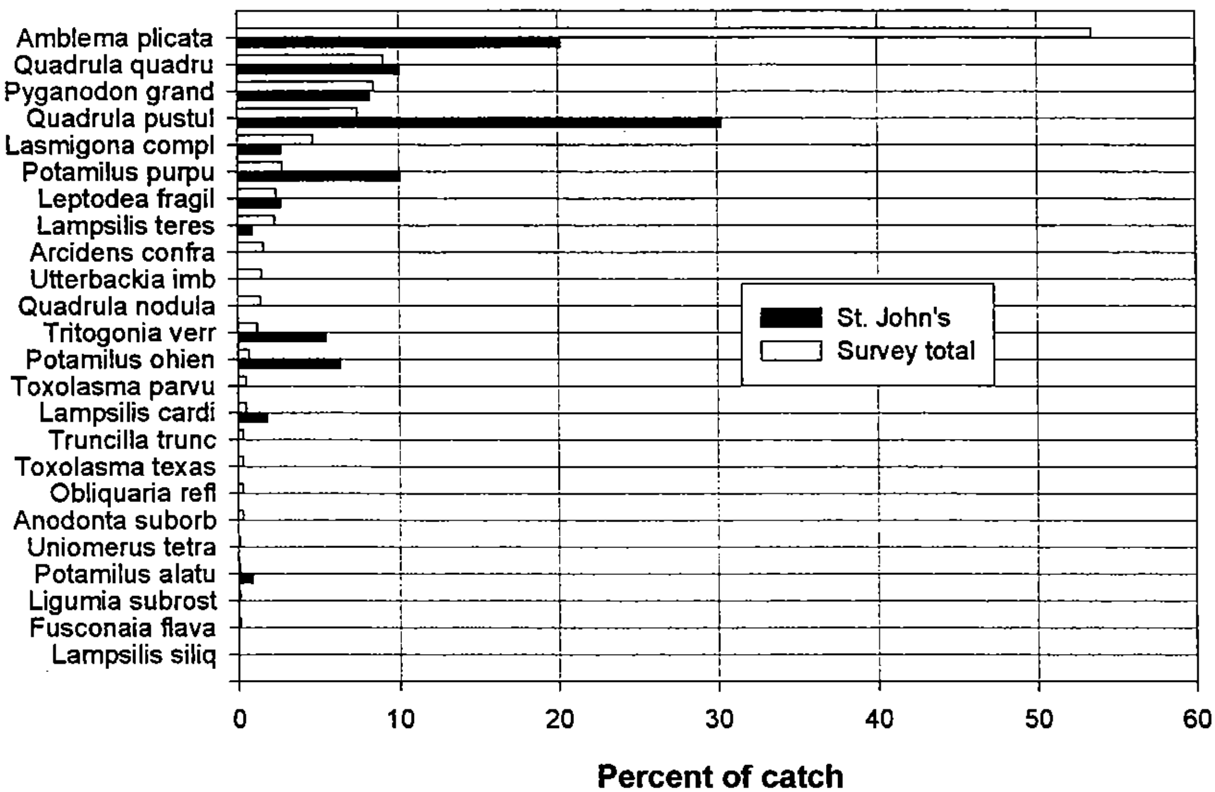


Figure 7. Relative species abundance in Setback Levee Ditch.

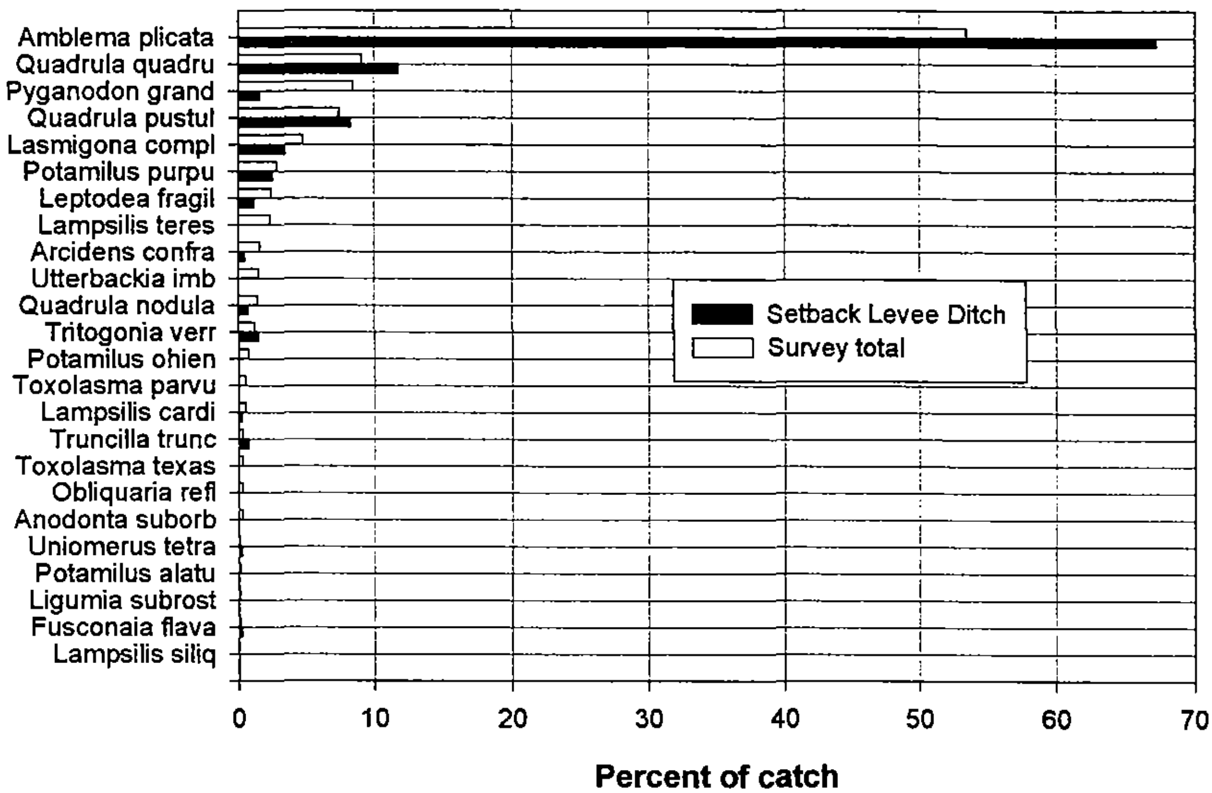


Figure 8. Relative species abundance in St. James Ditch.

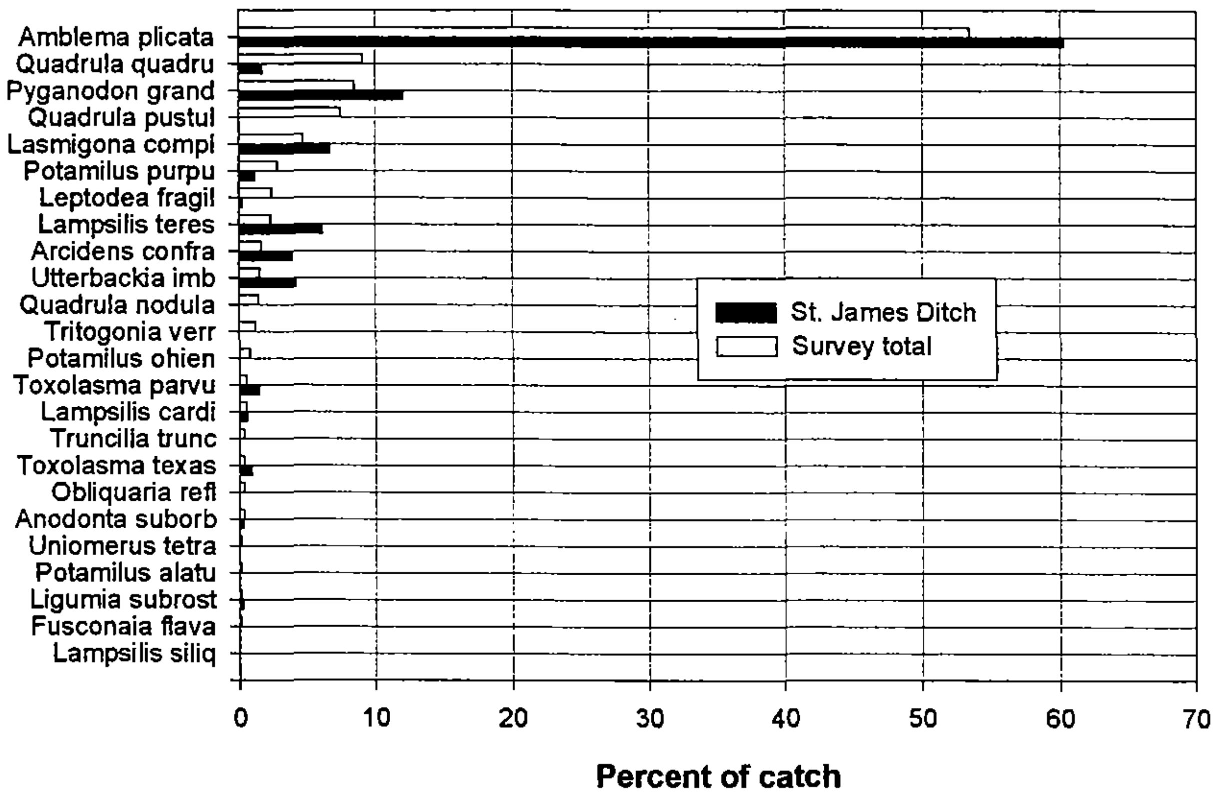


Figure 9. Relative species abundance in the New Madrid Floodway.

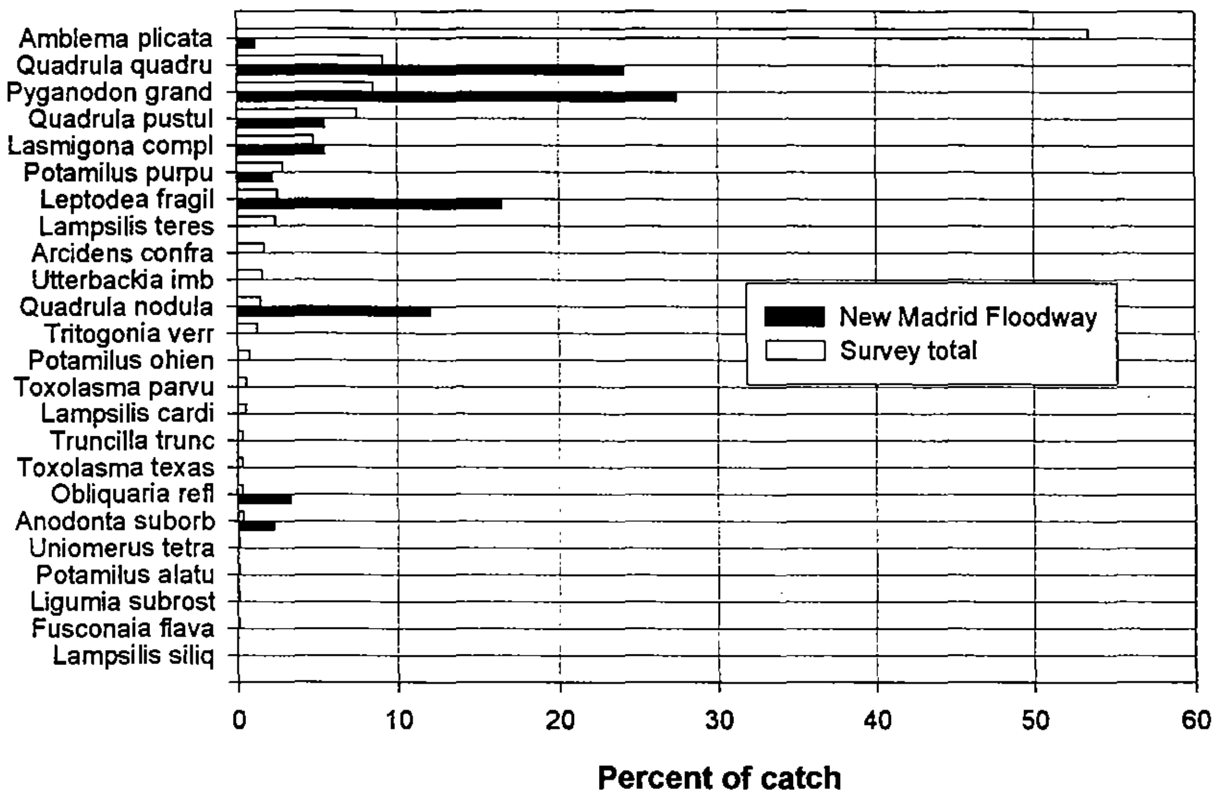


Figure 10. Difference between local and overall species abundance: St. John's Bayou and St. John's Ditch.

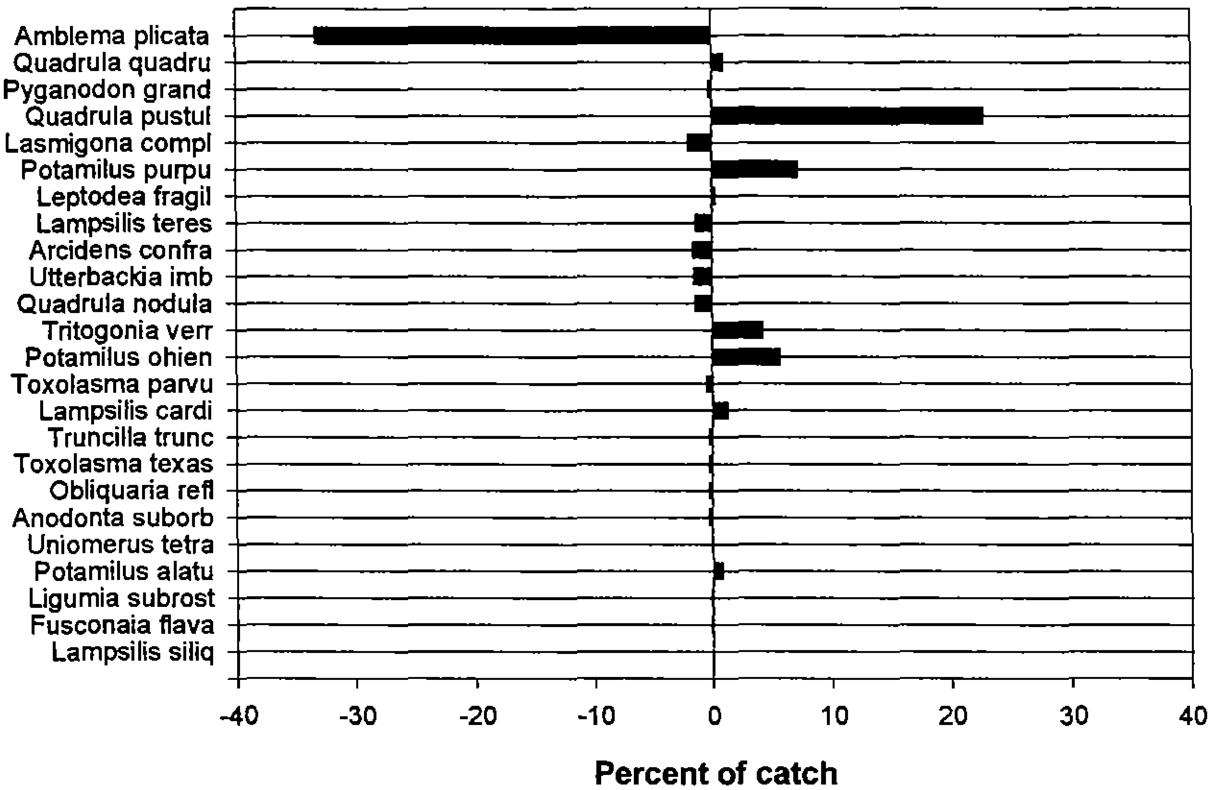


Figure 11. Difference between local and overall species abundance: Setback Levee Ditch.

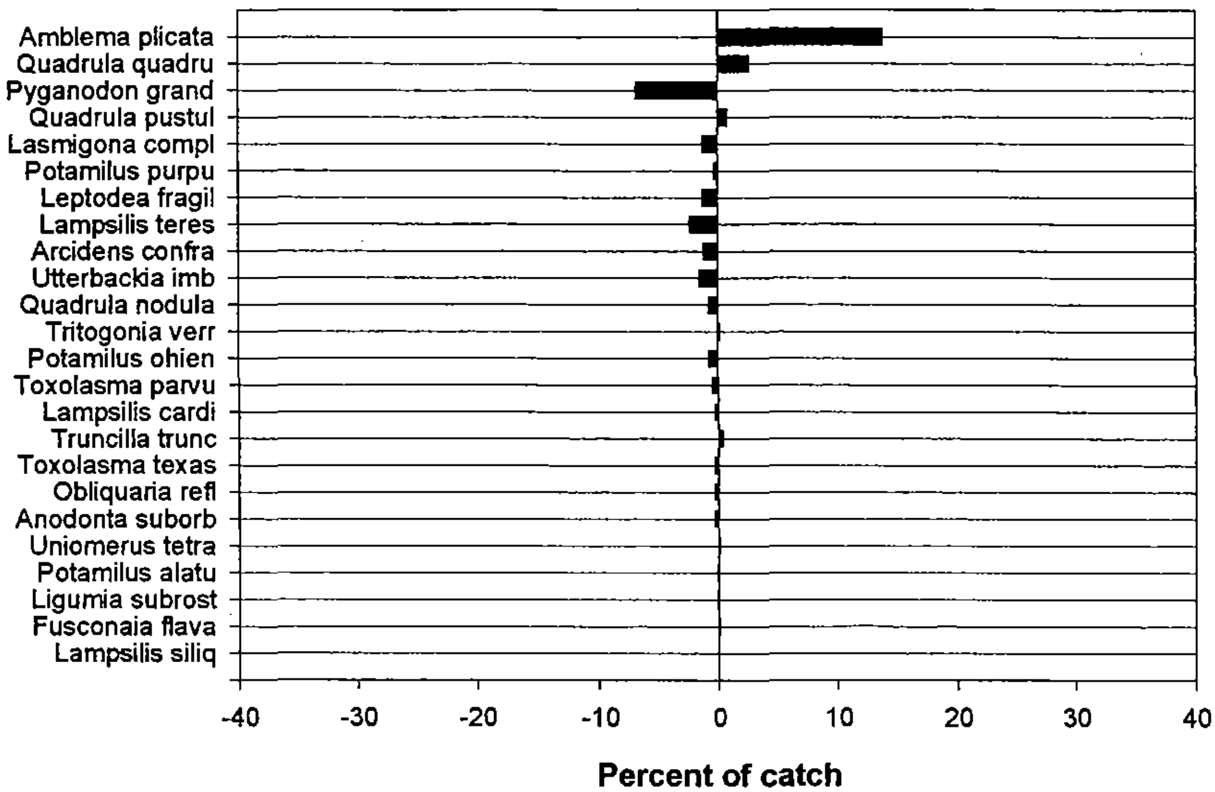


Figure 12. Difference between local and overall species abundance: St. James Ditch.

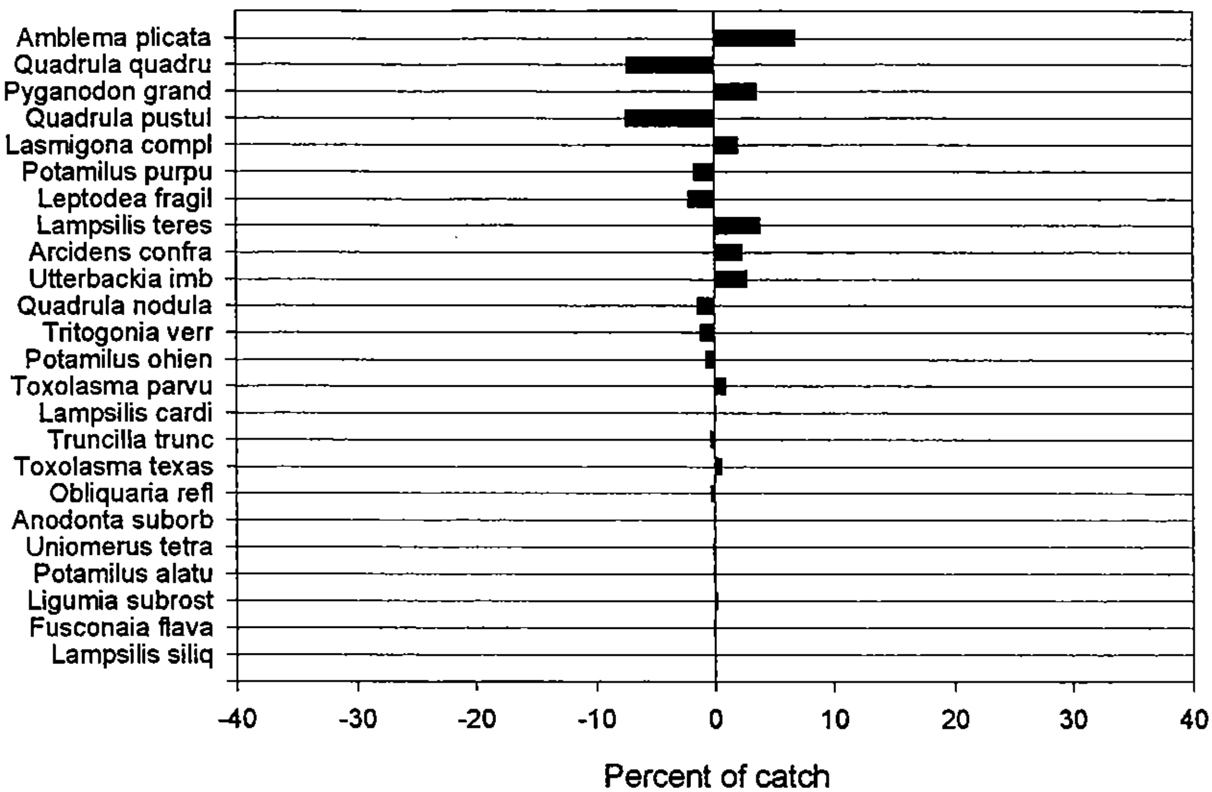


Figure 13. Difference between local and overall species abundance: New Madrid Floodway ditches.

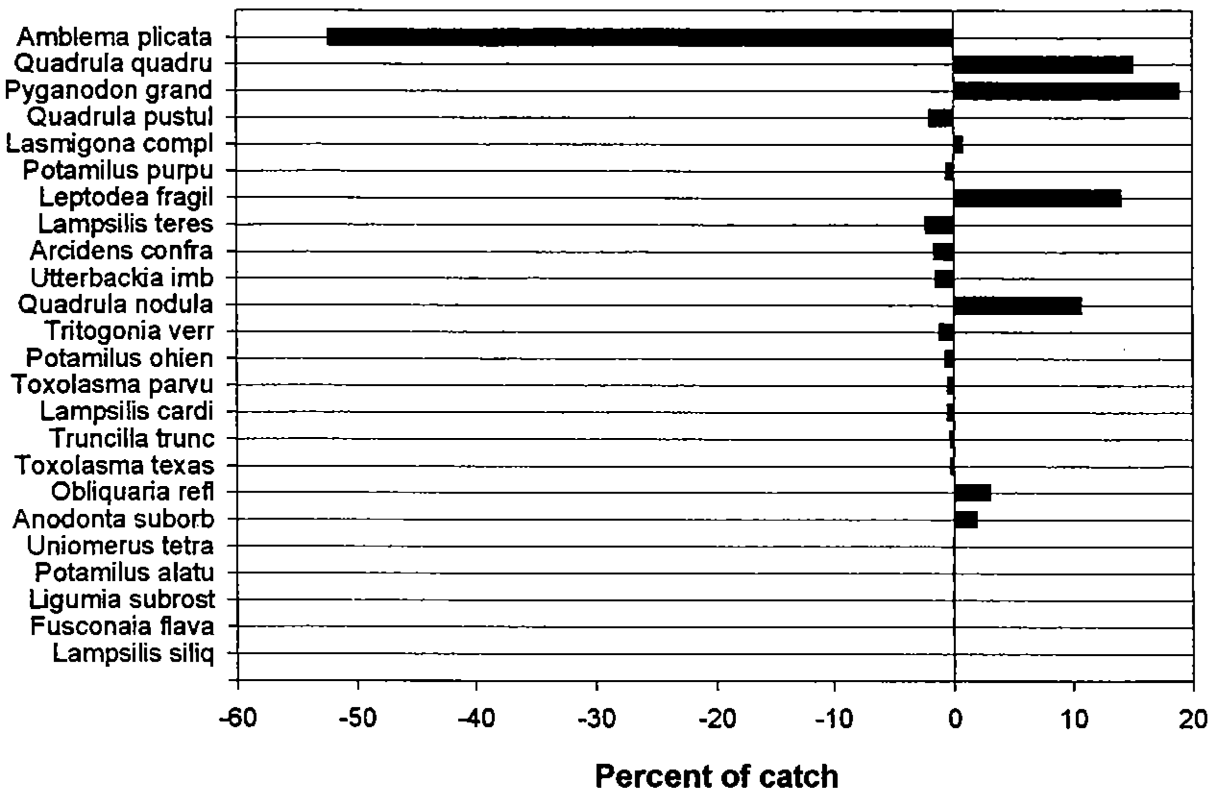


Figure 14. Catch per unit effort and number of species versus position upstream in St. James Ditch.

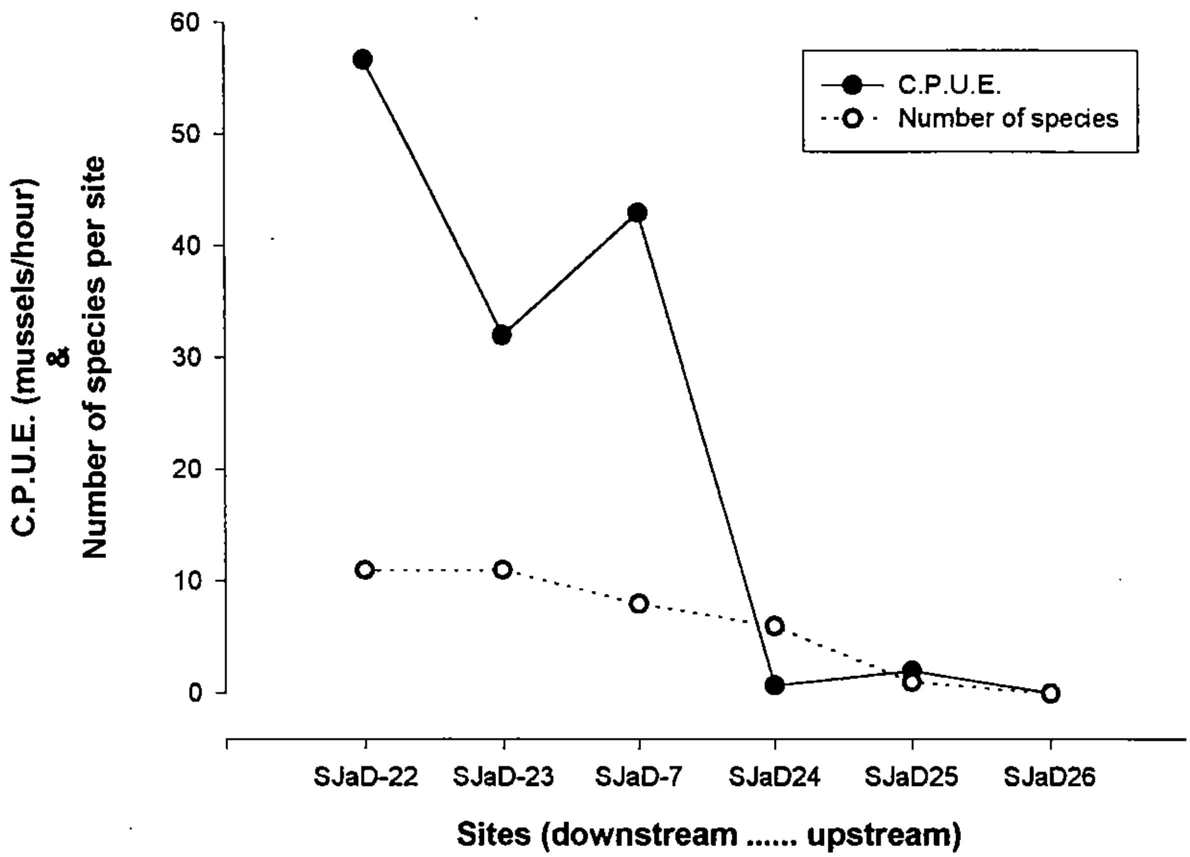


Figure 15. Relative abundance (percent of catch) by species in three ditch surveys in southeastern Missouri and northeastern Arkansas.

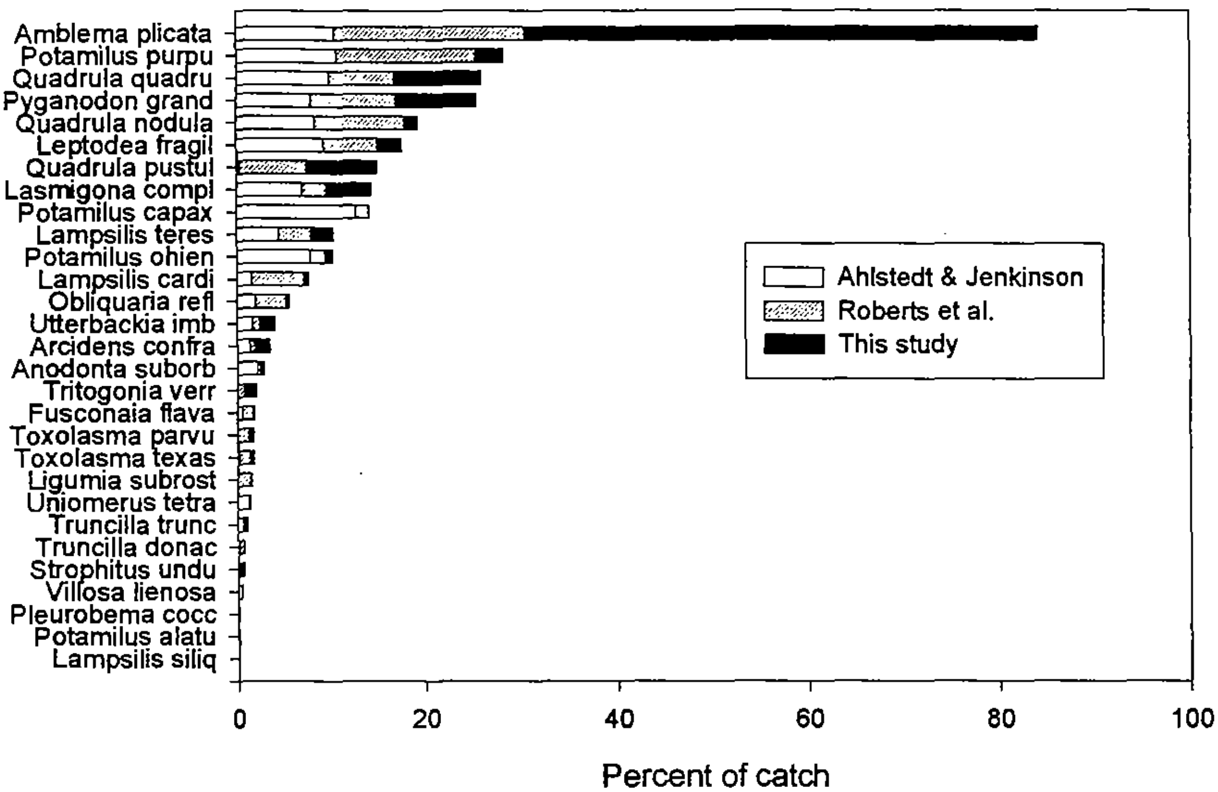


Figure 16. Number of sites at which each unionid species was found live in three ditch surveys in southeastern Missouri and northeastern Arkansas.

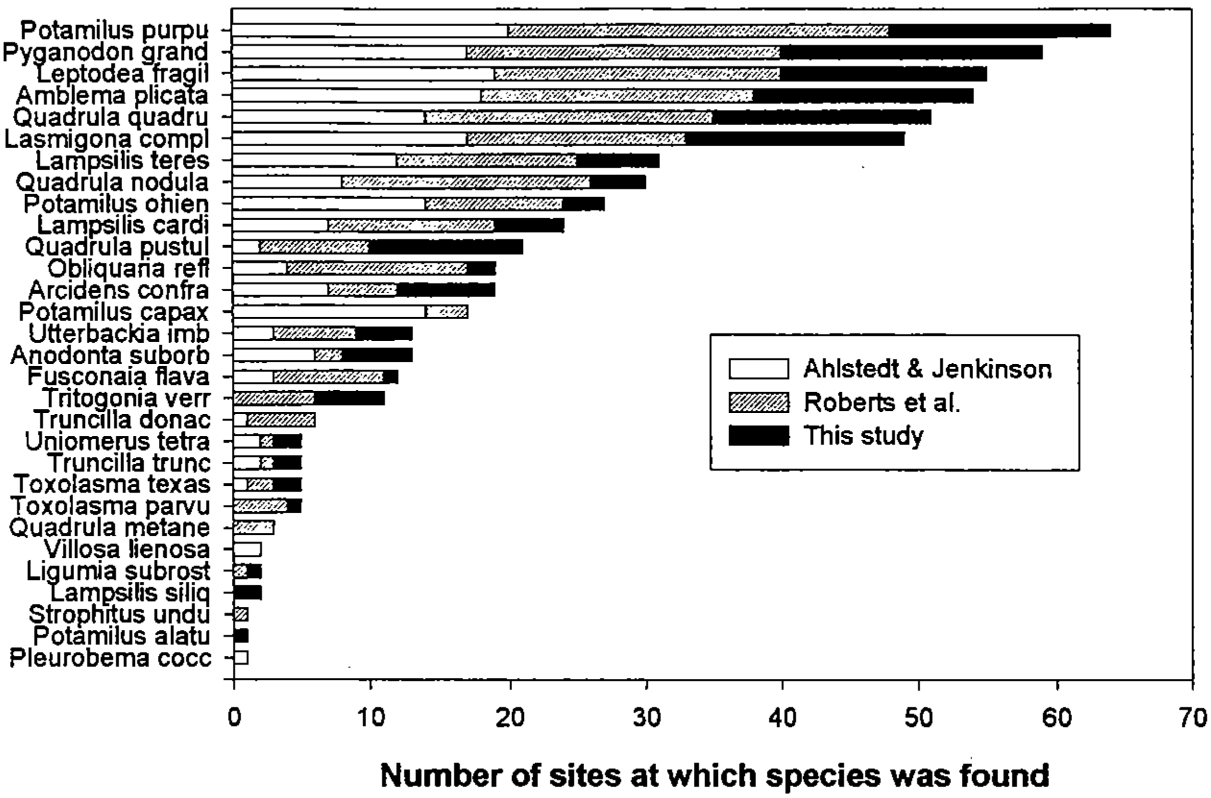


Figure 17. Shell length versus age estimated from annuli counts in *Amblema plicata* from Setback Levee Ditch and St. James Ditch.

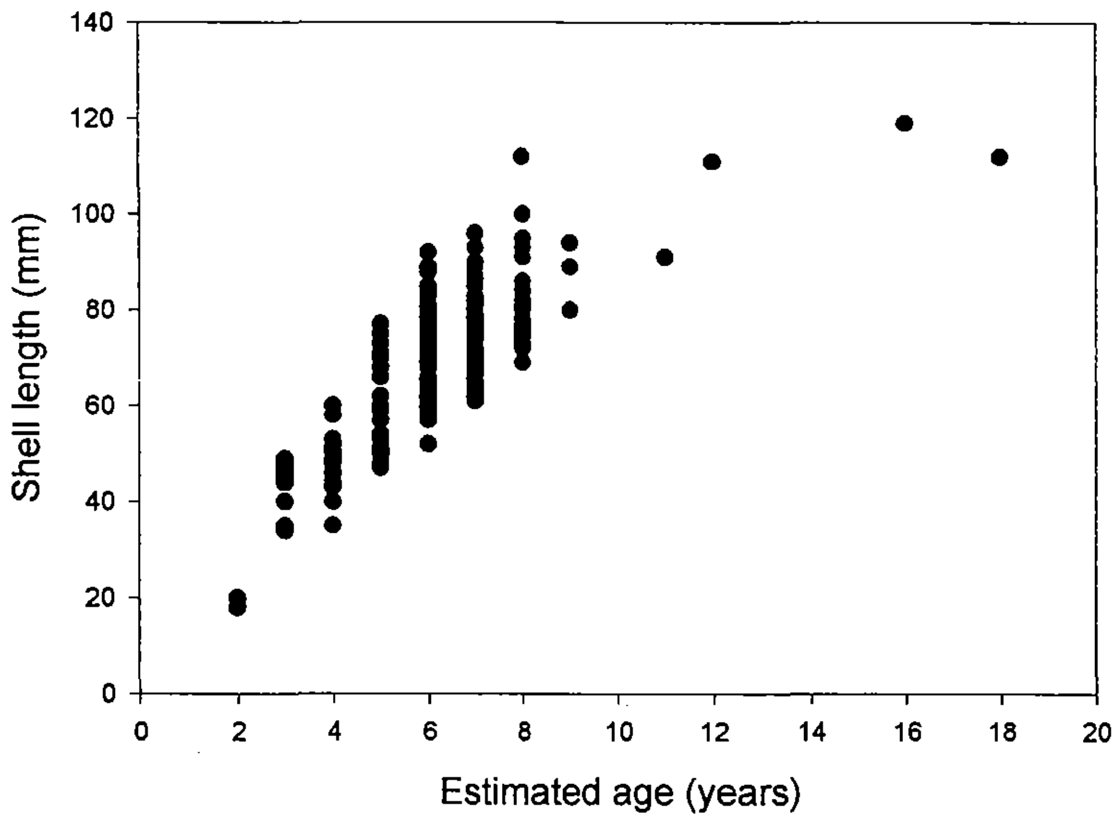


Figure 18. Length class frequency distribution of *Amblema plicata* from the Setback Levee Ditch.

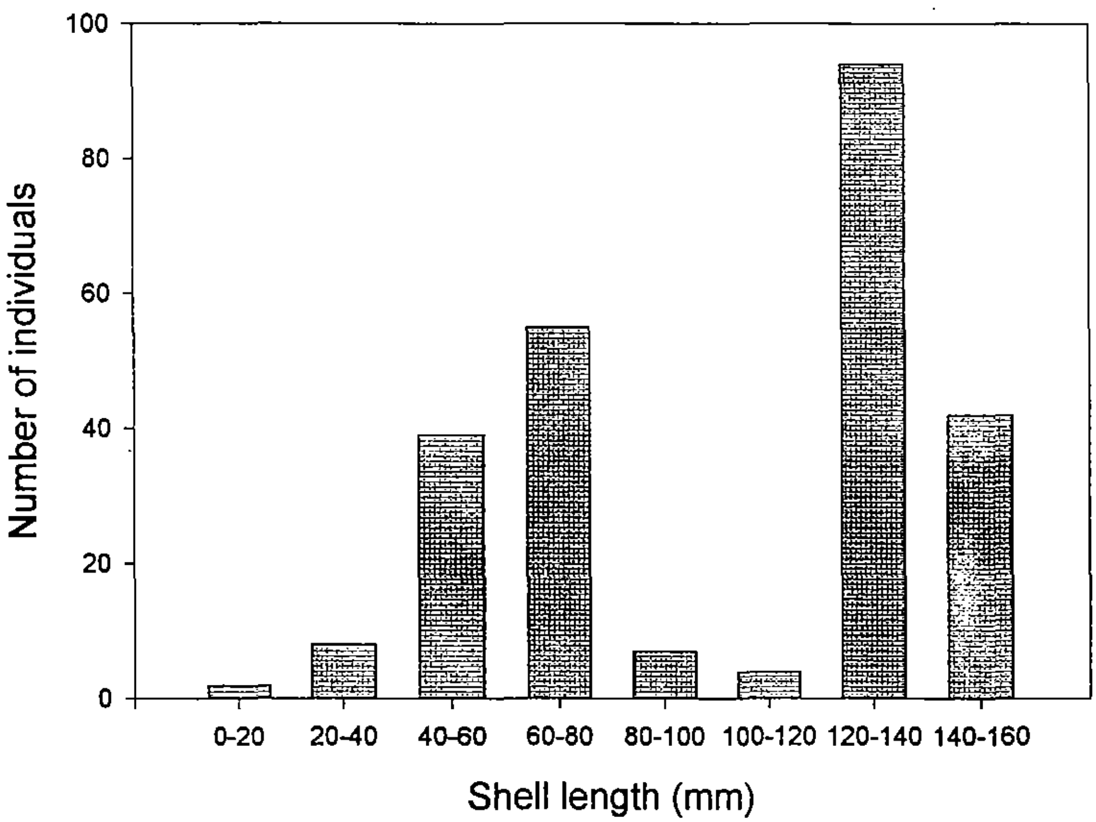


Figure 19. Length class frequency distributions of *Amblema plicata* from individual sites in the Setback Levee Ditch. Sites are arranged from upstream (top) to downstream (bottom) (Same data as Figure 18).

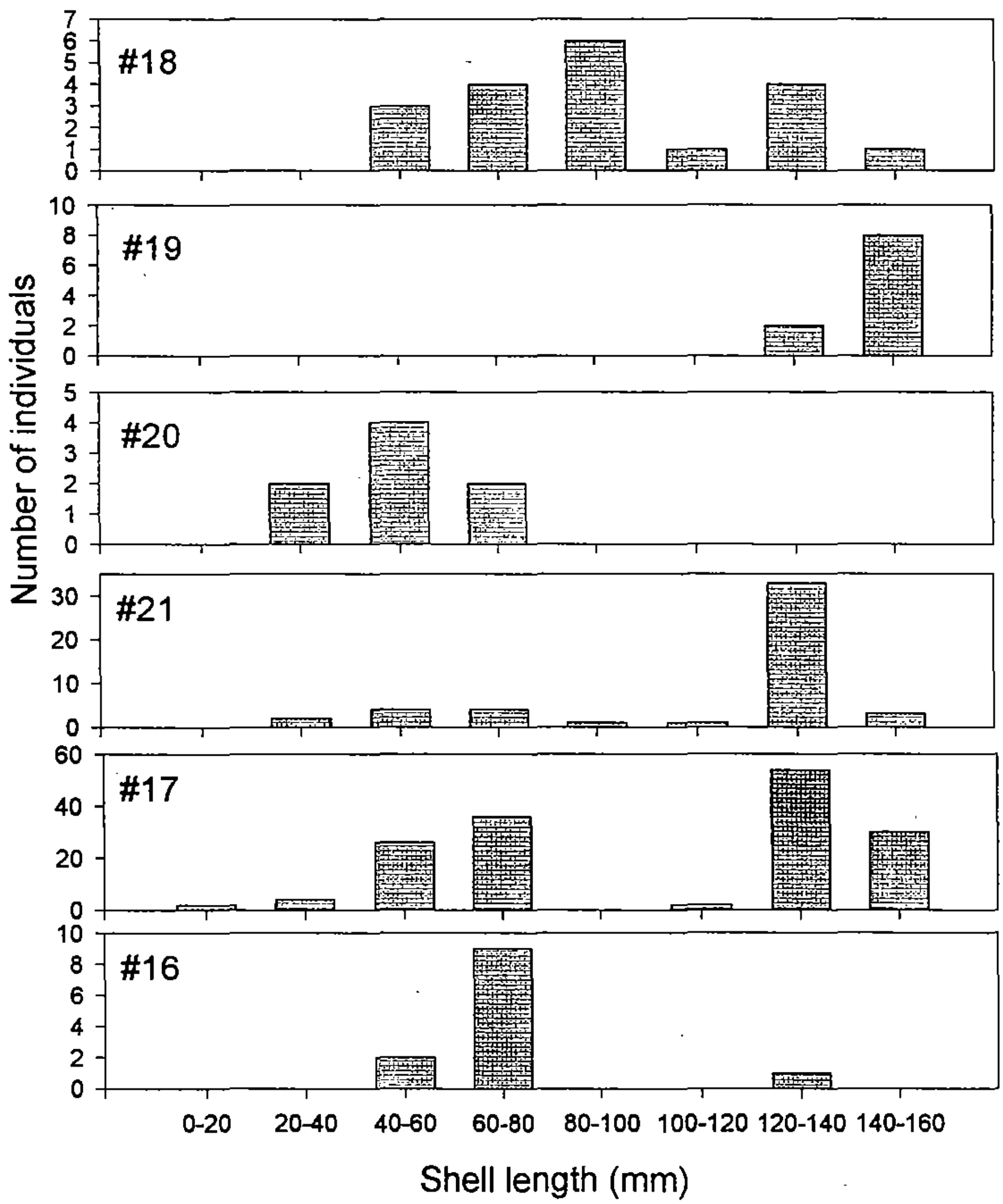
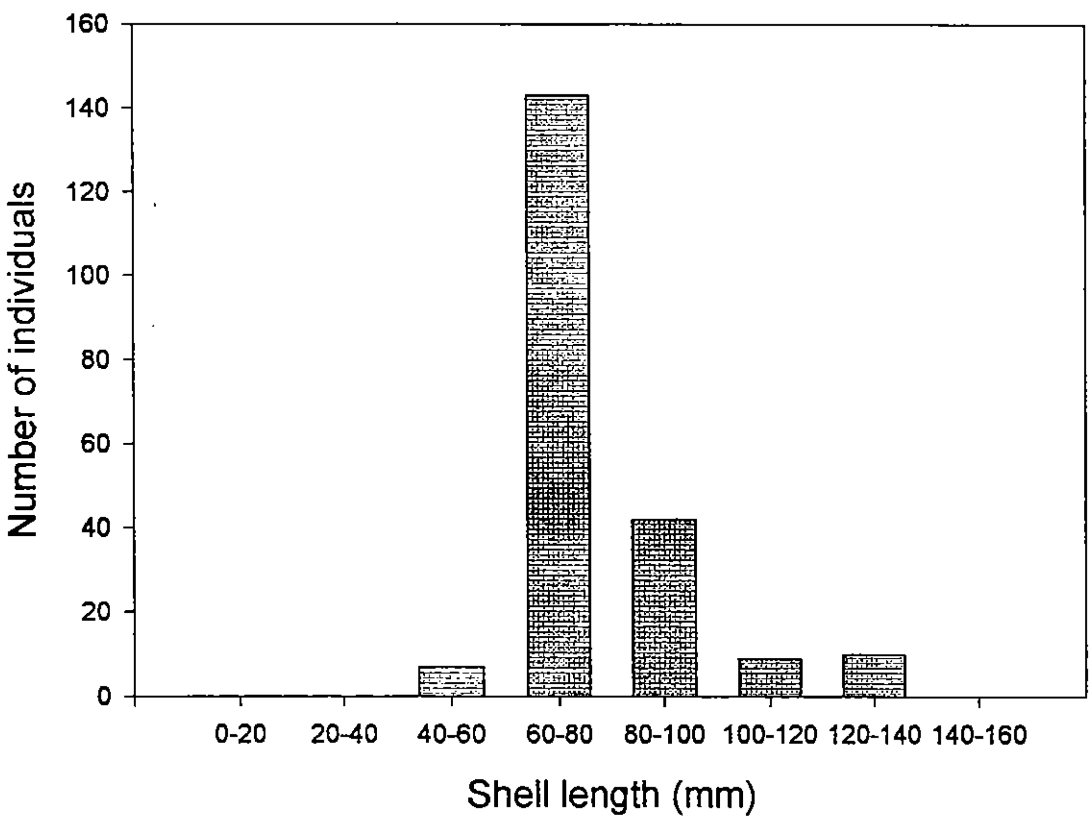


Figure 20. Length class frequency distributions of *Amblema plicata* from sites 7 and 22 in the St. James Ditch.



Site #: **NM-01-97**
Stream: St. John's Bayou Ditch
Date(s): 16 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 42.726 W089 29.340
Legal: Missouri; New Madrid Co., T24N R14E NE1/4 Sec. 24

Methods: Conducted 196 minutes of groping searches (BO=36; FR=50; DMH=55; DTH=55). Most mussels were collected along the left (east) side of ditch (i.e., ~2 meters from stream edge). We also sampled 16 quadrats (1/4 sq. m) immediately downstream from the qualitative sampling area.

Site description: Substrate consisted of fine, dark-colored sand, which was relatively uniform with depths ranging from 60 to 70 cm. The substrate seemed unstable since it was somewhat loose and had woody debris mixed in, suggesting recent disturbances. Although we did not note any recent dredging at this site, there was evidence of recent dredging (last 2 yrs) about 1/2 mile downstream. Flow in this ditch was fairly swift, which may also explain why the substrate was unstable. Ditch was approximately 29 m wide. Canopy was approximately 10%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	4	-	-	found near stream edge
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	1	-	-	found near stream edge
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	2	-	-	found near stream edge
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	1	-	2	found near stream edge
Pyganodon grandis	-	-	1	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	4	-	-	most found near stream edge
Quadrula quadrula	1	-	1	found near stream edge
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	1	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	-	
Total	**14**	**0**		

Corbiculidae

Corbicula fluminea	1	1	few	

Site #: **NM-02-97**
Stream: St. John's Bayou Ditch
Date(s): 16 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 41.141 W089 28.826

Legal: Missouri; New Madrid Co., T24N R15E SW1/4 Sec. 30

Methods: Conducted 240 minutes of groping searches (BO=60; FR=60; DMH=60; DTH=60). Most mussels were collected along the left (east) side of ditch (1 to 2 meters from stream edge). We also sampled 16 (1/4 sq. m) quadrats downstream from timed searches.

Site description: Substrate was similar to NM-01-97, with of fine, dark-colored sand. Depths ranged from 50 to 70 cm. The substrate seemed unstable since it was somewhat loose and had woody debris mixed in. The area looked like it had been dredged in the last year or two since there were no no mature trees, only annual weeds and young saplings, and because of recent dredge spoils along the left (east) bank. Ditch was approximately 34 m wide. Canopy was 0%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	8	-	-	found near edge of ditch (left)
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	2	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	1	-	-	found near edge of ditch (left)
Pyganodon grandis	-	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	22	-	-	most near edge; a few in mid-channel
Quadrula quadrula	2	-	-	found near edge of ditch (left)
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	1	-	-	found near edge of ditch (left)
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	-	
Total	**34**	**0**		

Corbiculidae

Corbicula fluminea	-	0	few	

Site #: **NM-03-97**
Stream: St. John's Bayou Ditch
Date(s): 17 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 39.415 W089 28.232

Legal: Missouri; New Madrid Co., T23N R15E SE1/4 Sec. 6

Methods: Conducted 120 minutes of groping searches (BO=30; FR=30; DMH=30; DTH=30). We concentrated most of our effort along edges of ditch. We also sampled 16 (1/4 sq. m) quadrats downstream from timed searches.

Site description: Substrate was similar to NM-01-97 & NM-02-97 in that it had fine, dark-colored sand, and because the substrate was loose and seemed unstable. Depths averaged about 60 cm. Width of ditch was approximately 37 m. Area did not appear to have been recently dredged, although there were no mature trees on banks. Canopy was 0%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	1	-	-	found near edge of ditch (right)
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	1	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	-	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	3	-	-	most near edge; a few in mid-channel
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	-	
Total	4	0		

Corbiculidae				
Corbicula fluminea	-	1	few	

Site #: **NM-04-97**
Stream: St. John's Bayou Ditch
Date(s): 17 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 37.644 W089 27.758

Legal: Missouri; New Madrid Co., T23N R15E NW1/4 Sec. 20

Methods: Conducted 120 minutes of groping searches (BO=30; FR=30; DMH=30; DTH=30). We concentrated most of our effort along the right edge of ditch (west) since there was mature vegetation on the right bank. We also sampled 16 (1/4 sq. m) quadrats downstream from timed searches.

Site description: Substrate was similar to NM-01-97 & NM-02-97 in that it had fine, dark-colored sand; however, the substrate seemed to be less stable, less uniform, and less compacted. Depths varied from 60 to 90 cm and width was approximately 37 m. There was a substantial area of timber on the left side of ditch and about a 75 wide band of timber on the right bank. The site is immediately upstream from the entrance of the "natural" bayou channel.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	1	-	-	found near edge of ditch (right)
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-		
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	1	-	-	found near edge of ditch (right)
Pyganodon grandis	-	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	1	-	-	found near edge of ditch (right)
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	-	
Total	3	0		

Corbiculidae

Corbicula fluminea	-	1	few	

Site #: **NM-05-97**
Stream: St. John's Bayou
Date(s): 17 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 36.667 W089 27.766

Legal: Missouri; New Madrid Co., T23N R15E NW1/4 Sec. 29

Methods: Conducted 120 minutes of groping searches (BO=30; FR=30; DMH=30; DTH=30).

Site description: Substrate was similar to NM-01-97 & NM-02-97 in that it had fine, dark-colored sand, and because the substrate was loose and seemed unstable. Depths varied from about 50 to 100 cm. Width of bayou was approximately 40 m. The area sampled was upstream about 25 m from old, iron bridge.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	-	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	-	
Total	0			

Corbiculidae

Corbicula fluminea	-	-	-	

Site #: **NM-06-97**
Stream: Wilkerson Ditch
Date(s): 18 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 41.407 W089 19.667

Legal: Missouri; New Madrid Co., T24N R16E S1/2 Sec. 28

Methods: Conducted 120 minutes of groping searches (BO=30; FR=30; DMH=30; DTH=30). We also sampled 20 quadrats.

Site description: Substrate consisted of fine, clean sand that seemed to be fairly unstable and loose. Area appeared to have been recently dredged (last 2 yrs) since there was little perennial vegetation on banks and because of dredge spoils. Depths ranged from 20 to 60 cm. Width of channel was 25 m. Canopy was 0%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	2	-	-	
Leptodea fragilis	6	-	2	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	-	-	-	
Quadrula nodulata	7	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	19	1	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	-	
Total	**34**	**1**		

Corbiculidae

Corbicula fluminea	-	1	-	

Site #: **NM-07-97**
Stream: St. James Ditch
Date(s): 18 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 45.643 W089 22.261

Legal: Missouri; New Madrid Co., T25N R16E SW1/4 Sec. 31

Methods: Conducted 120 minutes of groping searches (BO=40; FR=40; DTH=40) in a 10 m wide by 115 m long stretch of habitat.

Site description: Substrate consisted of fine sand and mud that seemed to be fairly stable. Substrate was covered in places with a layer of algae. Area searched did not seem to have been recently dredged because of mature perennial vegetation on the channel banks. Woody debris (e.g., fallen trees) was common in the channel. Canopy was ~85%. The channel was approximately 10 m wide. Depths were up to 1 m.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	70	-	-	
Arcidens confragosus	1	-	1	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	5	-	-	
Lampsilis siliquoidea	-	-	4	
Lasmigona complanata	3	-	-	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	4	-	5	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	3		-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	common	
Total	**86**			

Corbiculidae

Corbicula fluminea	C	-	A	

Site #: **NM-08-97**
Stream: Wilkerson Ditch
Date(s): 19 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 39.447 W089 19.697

Legal: Missouri; New Madrid Co., T23N R16E Sec. 4

Methods: Conducted 120 minutes of groping searches (BO=30; FR=30; DMH=30; DTH=30). We also sampled 20 quadrats.

Site description: Substrate consisted of fine, clean sand that seemed to be fairly unstable and loose. Area appeared to have been recently dredged (last 2 yrs) since there was little perennial vegetation on banks and because of dredge spoils. Lots of old stumps along shoreline. Water was very turbid. Depth ranged from 50 to 100 cm. Width was approximately 25 m. Canopy was 0%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	1	-	1	
Leptodea fragilis	2	1	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	1	
Pyganodon grandis	2	1	-	
Quadrula nodulata	2	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	1	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	-	
Total	**8**	**2**		

Corbiculidae

Corbicula fluminea	-	0	-	

Site #: **NM-09-97**
Stream: St. John's Diversion Ditch
Date(s): 19 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 38.418 W089 21.373

Legal: Missouri; New Madrid Co., T23N R15E Sec. 12

Methods: Conducted 120 minutes of groping searches (FR=40; DMH=40; DTH=40). We also sampled 24 quadrats.

Site description: Site was immediately downstream from an artifical fish weir. Substrate consisted of muddy sand with cleaner sand in mid-channel. Water was very turbid. Sampling was conducted at at depths to 80 cm. Channel width was approximately 14 m. Canopy cover was about 2%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	1	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	1	-	-	
Leptodea fragilis	6	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	2	2	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	1	-	-	
Pyganodon grandis	-	-	-	
Quadrula nodulata	2	-	-	
Quadrula pustulosa	5	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecilis	-	-	-	
Total	**18**	**2**		

Corbiculidae				
Corbicula fluminea	-	-	-	

Site #: **NM-10-97**
Stream: Mud Ditch
Date(s): 19 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 38.784 W089 23.353

Legal: Missouri; New Madrid Co., T23N R15E NE1/4 Sec. 16

Methods: Conducted 120 minutes of groping searches (BO=30; FR=30; DMH=30; DTH=30).

Site description: Substrate consisted of layers of sand, silt, and clay. Sampling was conducted at depths up to 70 cm. Channel width was about 25 m. Canopy was approximately 2%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	1	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	7	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	1	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	1	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	-	-	1	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	2	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	1	
Total	**3**			

Corbiculidae

Corbicula fluminea	-	-	-	

Site #: **NM-11-97**
Stream: Mud Ditch
Date(s): 19 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 36.137 W089 26.277

Legal: Missouri; New Madrid Co., T23N R15E SE1/4 Sec. 28

Methods: Conducted 80 minutes of groping searches (BO=20; FR=20; DMH=20; DTH=20).

Site description: Substrate consisted primarily of loose sand and mud. Areas near shore consisted of soupy mud. Sampling was conducted at depths of 10 to 40 cm. Width of area sampled was about 20 m. Canopy cover was 0%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	1.5	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	2	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	1	-	2	found outside timed search
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	1	
Total	**1**			

Corbiculidae

Corbicula fluminea	-	-	R	one valve

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Site #: **NM-12-97**
Stream: Mud Ditch
Date(s): 20 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 35.630 W089 26.368

Legal: Missouri; New Madrid Co., T23N R14E Sec. 36

Methods: Conducted 80 minutes of groping searches (BO=20; FR=20; DMH=20; DTH=20).

Site description: Substrate consisted of soupy mud with areas of sandy mud in mid-channel. Sampling was conducted at depths up to 80 cm, although depths exceeded 80 cm above and below the area sampled. Water was very turbid and warm. Canopy cover was 0%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	1	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	1	-	1	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	9	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**11**			

Corbiculidae

Corbicula fluminea	-	-	-	

Site #: **NM-13-97**
Stream: St. John's Bayou Ditch
Date(s): 21 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 44.691 W089 30.953

Legal: Missouri; New Madrid Co., T24N R14E NW1/4 Sec. 11

Methods: Conducted 240 minutes of groping searches (BO=60; FR=60; DMH=60; DTH=60).

Site description: Substrate consisted primarily of fine, dark colored sand that seemed fairly stable. It appeared that dredging had not occurred at this site in the past 10 years, although most of the live mussels were found near the timbered edge of the channel (left or east side). Depths up to 80 cm were sampled. Width at site was about 33 m.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	8	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	1	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	1	-	-	found outside timed search
Leptodea fragilis	1	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	1	-	3	
Pyganodon grandis	1	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	3	-	-	
Quadrula quadrula	7	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	4	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**27**			
Corbiculidae				
Corbicula fluminea	-	-	-	

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Site #: **NM-14-97**
Stream: Ten Mile Pond Ditch
Date(s): 21 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 45.077 W089 18.939

Legal: Missouri; New Madrid Co., T24N R16E SW1/4 Sec. 3

Methods: Conducted 160 minutes of groping searches (BO=40; FR=40; DMH=40; DTH=40).

Site description: Site is appoximately 30 m upstream from a concrete bridge on the MDC Tenmile Pon Wildlife Area. Substrate was mostly soft mud, although there was some sand mixed in, particularly in mid-channel. Water was very turbid and warm. Width of channel where we sampled was about 29 m.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	1	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	1	-	2	
Leptodea fragilis	-	-	1.5	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	1	-	-	
Pyganodon grandis	6	-	10	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	1	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**9**			

Corbiculidae

Corbicula fluminea	-	-	-	

Site #: **NM-15-97**
Stream: Ten Mile Pond Ditch
Date(s): 21 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 42.982 W089 20.093

Legal: Missouri; New Madrid Co., T24N R16E NE1/4 Sec. 17

Methods: Conducted 160 minutes of groping searches (BO=40; FR=40; DMH=40; DTH=40).

Site description: Substrate consisted of soupy mud with areas of woody debris. There were no signs of recent dredging. Depths ranged from 40 to 80 cm. Width of channel was about 23 m. Canopy was about 5%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	2	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	1	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	7	-	2	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	7			

Corbiculidae

Corbicula fluminea	-	-	-	

Site #: **NM-16-97**
Stream: Spillway Ditch (Setback Levee Ditch)
Date(s): 22 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 37.735 W089 26.436

Legal: Missouri; New Madrid Co., T23N R15E NW1/4 Sec. 21

Methods: Conducted 240 minutes of groping searches (BO=60; FR=60; DMH=60; DTH=60). We also sampled 24 quadrats.

Site description: We sampled upstream from old concrete bridge. Substrate consisted of firm sand, wit a few areas of soft mud. The left bank was void of mature perennial vegetation, whereas the right bank (west) was well timbered. Most of the live mussels were found along the right edge (within 2-3 m) of channel. Depths varied from 20 to 50 cm. Width of channel was about 15 m. Canopy was ~8%.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	12	2	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	1	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	2	-	-	
Leptodea fragilis	2	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	1	-	2	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	4	-	-	
Quadrula quadrula	8	3	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	1	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	30	5		

Corbiculidae

Corbicula fluminea	R	6	R	

Site #: **NM-17-97**
Stream: Spillway Ditch (Setback Levee Ditch)
Date(s): 22 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, Darby M. Hansen, and Dave T. Howlett

Locality:
Lat/Long: N 36 44.428 W089 24.098

Legal: Missouri; New Madrid Co., T23N R15E NW1/4 Sec. 2

Methods: Conducted 180 minutes of groping searches (BO=60; FR=30; DMH=30; DTH=60). We also sampled 24 quadrats.

Site description: Substrate consisted of relatively clean, firm sand, except along the channel edge where some mud was encountered. The left or east bank was relatively free of mature perennial vegetation, suggesting recent dredging activities. The right or west bank had mature trees. The area sampled was immediately upstream from a concrete bridge. Channel width was ~19 m. Canopy was ~5%. Sampling depths varied from 30 to 60 cm. Most unionids were found near the right edge of channel. Specimens collected in mid-channel tended to be 5 years and younger.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	194	1	3	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	0.5	old shell
Lampsilis cardium	1	-	0.5	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	1	-	-	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	2	-	-	
Pyganodon grandis	1	-	-	
Quadrula nodulata	3	-	-	
Quadrula pustulosa	5	-	-	
Quadrula quadrula	24	1	1	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	3	-	-	
Truncilla truncata	2	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**236**	**2**		
Corbiculidae				
Corbicula fluminea	R	1	R	

Site #: **NM-18-97**
Stream: Spillway Ditch (Setback Levee Ditch)
Date(s): 31 July 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 43.336 W089 21.837

Legal: Missouri; New Madrid Co., T24N R16E Sec. 18

Methods: Conducted 150 minutes of groping searches (BO=50; FR=50; DTH=50).

Site description: Substrate consisted of fine, relatively compacted sand. Depth of site was generally shallow (20-40 cm), although some areas were about 60 cm deep. Most mussels were found along the extreme right or west side of channel. Like site 16 &17, the left or east bank was void of mature vegetation. Width of channel was ~12 m.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	19	-	3	
Arcidens confragosus	1	-	0.5	
Fusconaia flava	1	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	1	-	1	
Leptodea fragilis	2	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	2	-	0.5	
Pyganodon grandis	2	-	0.5	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	1	-	0.5	
Quadrula quadrula	4	-	1	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	3	-	1	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	1	-	-	
Utterbackia imbecillis	-	-	-	
Total	**37**			

Corbiculidae

Corbicula fluminea	A	-	A	

Site #: **NM-19-97**
Stream: Spillway Ditch (Setback Levee Ditch)
Date(s): 1 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 44.886 W089 21.301

Legal: Missouri; New Madrid Co., T24N R16E SW1/4 Sec. 5

Methods: Conducted 120 minutes of groping searches (BO=40; FR=40; DTH=40).

Site description: Substrate was predominantly sand with areas of mud along the edge of channel. Channel width was approximately 12 m. Depths ranged from 20 to 60 cm.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	10	-	1	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	0.5	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	3	-	-	
Leptodea fragilis	-	-	1	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	4	-	0.5	
Pyganodon grandis	1	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	4	-	2	
Quadrula quadrula	4	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**26**			

Corbiculidae

Corbicula fluminea	A	-	A	

Site #: **NM-20-97**
Stream: Spillway Ditch (Setback Levee Ditch)
Date(s): 1 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 41.975 W089 22.455

Legal: Missouri; New Madrid Co., T24N R15E NE1/4 SE1/4 Sec. 25

Methods: Conducted 120 minutes of groping searches (BO=40; FR=40; DTH=40).

Site description: Substrate consisted mostly of sand, although the sand was mixed with more silt than other Spillway Ditch sites. Area appeared to have been recently altered. A small channel converges int the main channel on the right side. We sample both the main channel and the small feeder ditch. Widt of the main channel was between 11 and 12 m. Depth ranged from 20 to 30 cm. Canopy was 1%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	8	-	-	
Arcidens confragosus	1	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	7	-	-	
Leptodea fragilis	1	-	2	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	3	-	2	
Pyganodon grandis	2	-	2	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	1	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**23**			

Corbiculidae

Corbicula fluminea	A	-	A	

Site #: **NM-21-97**
Stream: Spillway Ditch (Setback Levee Ditch)
Date(s): 1 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:

Lat/Long: N 36 38.954 W089 25.547

Legal: Missouri; New Madrid Co., T23N R15E W1/2 Sec. 10

Methods: Conducted 120 minutes of groping searches (BO=40; FR=40; DTH=40).

Site description: Substrate consisted of relatively clean, fine sand, with areas of mud along the extrem edge of ditch. Live mussels were found mostly along the right side of channel, which corresponded with the presence of mature, overhanging trees. The left bank was void of mature perennial vegetation. Wid of channel varied from 14 to 19 m. Depths ranged from 20 to 60 cm. Canopy was ~ 2%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	48	-	2	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	1	-	-	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	-	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	22	-	1	
Quadrula quadrula	10	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**81**			

Corbiculidae				
Corbicula fluminea	-	-	-	

Site #: **NM-22-97**
Stream: St. James Ditch
Date(s): 2 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:

Lat/Long: N 36 42.169 W089 23.443

Legal: Missouri; New Madrid Co., T24N R15E SE1/4 Sec. 23

Methods: Conducted 180 minutes of groping searches (BO=60; FR=60; DTH=60). We also sampled 28 quadrats.

Site description: Substrate consisted of fine mud. Many of the trees along the bank were recently cut. Ditch did not appear to have been recently dredged. Channel width was 10 to 11 m. Depths ranged fro 10 to 40 cm. Canopy was ~10%.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	141	12	1	
Arcidens confragosus	7	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	1	-	-	
Lampsilis teres	2	-	2	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	9	-	2	
Leptodea fragilis	1	1	1	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	2	-	-	
Pyganodon grandis	2	-	5	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	3	-	1	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	1	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	2	-	5	
Total	**170**	**13**		

Corbiculidae

Corbicula fluminea	C	-	F	

Site #: **NM-23-97**
Stream: St. James Ditch
Date(s): 2 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 43.705 W089 23.484

Legal: Missouri; New Madrid Co., T24N R15E NE1/4 Sec. 14

Methods: Conducted 180 minutes of groping searches (BO=60; FR=60; DTH=60).

Site description: Substrate consisted of soupy mud. Channel was approximately 11 m wide. Depths ranged from 20 to 70 cm.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	1	-	2	
Amblema plicata	3	-	-	
Arcidens confragosus	6	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	15	-	1	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	12	-	0.5	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	1	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	2	-	-	
Pyganodon grandis	35	-	9	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	5	-	-	
Toxolasma texasensis	3	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	13	-	8	
Total	**96**	**0**		

Corbiculidae

Corbicula fluminea	A	-	A	

Site #: **NM-24-97**
Stream: St. James Ditch
Date(s): 3 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 47.419 W089 21.984

Legal: Missouri; New Madrid Co., T25N R16E SW1/4 Sec. 19

Methods: Conducted 90 minutes of visual and groping searches (BO=30; FR=30; DTH=30).

Site description: Substrate consisted of sand. Channel was somewhat braided, and depths varied considerably (10 to 90 cm). Width of channel was between 5 and 8 m. Much of the sand substratum covered with a layer of algae. Banks were void of trees. Water was very clear. Fish were abundant.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	1	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	1	-	0.5	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	6	
Lasmigona complanata	-	-	1	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	1.5	
Pyganodon grandis	-	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	1			

Corbiculidae

Corbicula fluminea	F	-	C	

Site #: **NM-25-97**
Stream: St. James Ditch
Date(s): 3 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 49.165 W089 22.439

Legal: Missouri; New Madrid Co., T25N R16E SW1/4 Sec. 7

Methods: Conducted 60 minutes of groping searches (BO=20; FR=20; DTH=20).

Site description: Substrate consisted of sand with areas of woody debris. Much of the substrate was with algae. Water visibility was excellent. Depths varied from 30 to 120 cm. Width of channel average about 8 m.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	2	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**2**			

Corbiculidae

Corbicula fluminea	-	-	-	

Site #: **NM-26-97**
Stream: St. James Ditch
Date(s): 3 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 50.016 W089 22.434

Legal: Missouri; New Madrid Co., T25N R16E SW1/4 Sec. 6

Methods: Conducted 60 minutes of groping searches (BO=20; FR=20; DH=20).

Site description: Substrate consisted of sand, with much of it covered with algae. There was also a lot of old plant debris covering the the substrate. Depths up to 1 m were found. Width of channel was abou 8 m.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	-	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	-	
Potamilus purpuratus	-	-	-	
Pyganodon grandis	-	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**0**			

Corbiculidae

Corbicula fluminea	-	-	-	

Site #: **NM-27-97**
Stream: St. John's Bayou's confluence with Mississippi River
Date(s): 4 August & 20 September 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave Howlett & M. Chris Barnhart and B. Obermeye

Locality:
Lat/Long: N 36 34.991 W089 31.015

Legal: Missouri; New Madrid Co., T23N R14E Sec. 35

Methods: Conducted120 minutes of groping searches (BO=60;MCB=60). We also took 10 Ekman dredge samples (4 Aug.).

Site description: Site appearance varied considerably between the first vist in early August and the second visit in September, which was due to lower water conditions in the Mississippi River. The substrate, which consisted of mud, seemed very unstable. Maximum depth during the 2nd search was about 1.4 m. Width of the Bayou channel was about 18 m, but the width of area searched at the mouth of Morrison Chute was about 90 m.

Unionid species	**Live**		**Dead**	**Comments**
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	-	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	2	-	present	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	1	-	present	
Potamilus ohiensis	7	-	present	
Potamilus purpuratus	4	-	-	
Pyganodon grandis	4	-	present	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	-	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**18**			

Corbiculidae

Corbicula fluminea	C	-	C	

Site #: **NM-28-97**
Stream: St. John's Bayou - just downstream from water control structure
Date(s): 4 August 1997
Collector(s): Brian Obermeyer, Frank Riusech, and Dave T. Howlett

Locality:
Lat/Long: N 36 35.431 W089 30.648

Legal: Missouri; New Madrid Co., T23N R14E Sec. 35

Methods: Conducted 30 minutes of groping searches (BO=30).

Site description: Substrate, which consisted of soupy mud, seemed to be very unstable, especially in mid-channel. Area sampled was along the west or right side of channel just downstream from the water control structure. Width of channel was about 25 m. Canopy was 0%.

Unionid species	Live		Dead	Comments
	qualitative	quadrats		
Anodonta suborbiculata	-	-	-	
Amblema plicata	-	-	-	
Arcidens confragosus	-	-	-	
Fusconaia flava	-	-	-	
Lampsilis cardium	-	-	-	
Lampsilis teres	1	-	-	
Lampsilis siliquoidea	-	-	-	
Lasmigona complanata	-	-	-	
Leptodea fragilis	-	-	1	
Ligumia subrostrata	-	-	-	
Obliquaria reflexa	-	-	-	
Potamilus alatus	-	-	-	
Potamilus ohiensis	-	-	1	
Potamilus purpuratus	3	-	-	
Pyganodon grandis	4	-	-	
Quadrula nodulata	-	-	-	
Quadrula pustulosa	-	-	-	
Quadrula quadrula	1	-	-	
Toxolasma parvus	-	-	-	
Toxolasma texasensis	-	-	-	
Tritogonia verrucosa	-	-	-	
Truncilla truncata	-	-	-	
Uniomerus tetralasmus	-	-	-	
Utterbackia imbecillis	-	-	-	
Total	**9**			

Corbiculidae				
Corbicula fluminea	-	-	-	

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Freshwater Mussel Survey
Mud Ditch and St. Johns Bayou Basin,
New Madrid County, Missouri

Introduction

The purposes of this mussel survey were to conduct a pre-construction survey of Mud Ditch in the New Madrid Floodway and conduct a preliminary survey of the St. Johns Bayou Basin. A closure levee is scheduled to be constructed across Mud Ditch. Four 10-foot by 10-foot gated box culverts will be constructed across Mud Ditch at the closure location.

Several construction items are scheduled in the St. Johns Bayou Basin. These items consist of channel enlargement of the lower 4.5 miles of St. Johns Bayou, 8.1 miles of Setback Levee Ditch, and 7.1 miles of St. James Ditch. Preliminary surveys were conducted to determine if previous surveys (Barnhart, 1998) were still accurate with present day conditions, determine relocation sites, and determine methods for implementing long term monitoring of the freshwater mussel resource. Previous National Environmental Policy Act Documents recommended relocating a portion of the population of Setback Levee Ditch and conducting long term monitoring over a 10-year time period to measure recolonization following channel alteration.

Barnhart (1998) surveyed a total of 28 sites within the St. Johns Bayou Basin and the New Madrid Floodway. The study area supports a diverse and fairly abundant unionid fauna consisting of at least 24 species that are typical of drainage canals of the lower Mississippi lowlands in Missouri and Arkansas. The seven most abundant species found, in order of abundance, were *Amblema plicata, Quadrula quadrula, Pyganadon grandis, Q. pustulosa, Lasmigona complanata, Potamilus purpuratus,* and *Leptodea fragilis*. The survey found four species that are considered rare within the State of Missouri. These species are *Arcidens confragosus, Anodonta suborbiculata, Q. nodulata,* and *Toxolasma texasensis.*

Methods

Qualitative freshwater mussel surveys were conducted between 13 and 15 June 2005 in 14 sites (Figure 1). Surveys were conducted my members of the U.S. Fish and Wildlife Service, Missouri Ecological Services Columbia Field Office and the U.S. Army Corps of Engineers, Memphis District Environmental Branch. Hand searches were conducted by diving, snorkeling, and wading to locate freshwater mussels. Survey sites were approximately 100 meters in length and all available microhabitats within the survey reach were sampled. A minimum of 0.3 person hours were spent at each site. Searches were continued at least 0.25 person hours after the last new species was encountered. Mussels encountered (live and fresh dead) were enumerated and placed back in the substrate from where they were found. Mussels were occasionally placed in cloth mesh

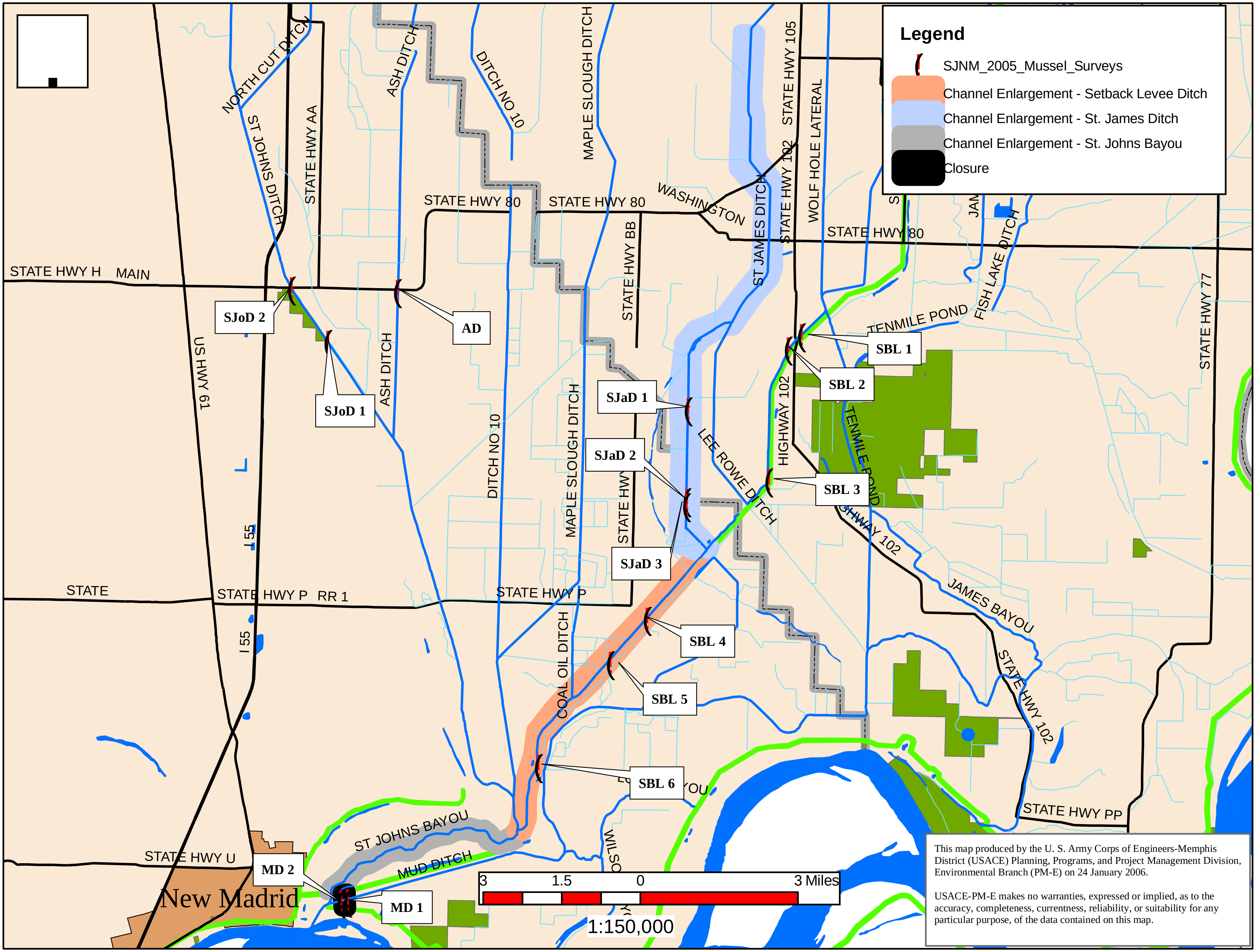

Figure 1. Freshwater mussel survey locations, St. Johns Bayou Basin and Mud Ditch, June 2005, Missouri.

bags, kept submerged, and brought to the surface for identification. Once identified, mussels were returned to the substrate from where they were found.

Results

Tables 1 and 2 provide results. A total of 802 live individuals representing 14 species were collected from 14 different sites. The upper reaches of Setback Levee Ditch yielded the highest number of live species. St. James Ditch yielded the greatest catch per unit effort. No mussels were found in the lower section of Mud Ditch, St. Johns Ditch at Highway 80, and Ash Ditch at Highway 80.

A. plicata was distributed most widely (10 sites) followed by *L. complanata* (9 sites), Q. *quadrula* (9 sites) *L. teres* (8 sites), *P. purpuratus* (8 sites), and *P. grandis* (8 sites). No Federally listed threatened or endangered species were found in the survey. State listed rare species found include *A. suborbiculata* (1 relic shell) and *A. confragosus (*six sites).

Substrate varied throughout the survey sites. Table 3 provides information on the general habitat type and substrate of the sample sites.

Discussion

Figure 2 provides survey results from the present survey, surveys conducted in the summer of 2004, and surveys conducted by Barnhart (1998).

<u>Mud Ditch</u>

One *P. grandis* was found in the levee closure location of Mud Ditch. Barnhart (1998) sampled Mud Ditch approximately 4,000 feet upstream of the construction zone. Table 4 provides data from the current survey and Barnhart's (1998) earlier survey.

Barnhart found three species of live mussels as compared to one species in the present survey. Sampling was conducted by wading (depths were approximately 80 cm) in Barnhart's (1998) survey while sampling entailed diving (depths exceeded three meters) in the present survey. The differences in survey methods may explain the small differences in survey results. However, the freshwater mussel community within the lower section of Mud Ditch does not appear to be significant. No further freshwater mussel surveys of the lower portion of Mud Ditch are planned.

<u>St. Johns Bayou Basin</u>

St. Johns Ditch downstream of the Swift Ditch area (SJoD 1) supported a moderate number of species observed (8 species) but a low number of CPUE (9.6). No construction is proposed in this section of St. Johns Ditch. This section of channel may offer suitable habitat to relocate a portion of the mussels from Setback Levee Ditch or St. James Ditch.

Table 1. Freshwater mussel survey locations, St. Johns Bayou Basin and Mud Ditch, Missouri.

Site	Date	Latitude (dd.dddd)	Longitude (dd.ddddd)	Reach (meters)	Search Time (minutes)	Survey Method
Mud Ditch 1	13 June 2005	36.590290	-89.504289	100	36	Scuba
Mud Ditch 2	13 June 2005	36.589935	-89.506563	50	20	Scuba
St. Johns Ditch 1	14 June 2005	36.744720	-89.516130	200	150	Hand
St. Johns Ditch 2	14 June 2005	36.759207	-89.529115	90	27	Scuba
Ash Ditch	14 June 2005	36.759280	-89.492740	200	100	Hand/Snorkel
St. James Ditch 1	14 June 2005	36.728597	-89.391736	50	100	Hand/Snorkel
St. James Ditch 2	14 June 2005	36.703359	-89.391426	100	90	Hand/Snorkel
St. James Ditch 3	14 June 2005	36.702065	-89.391539	75	40	Hand/Snorkel
Setback Levee Ditch 1	14 June 2005	36.748090	-89.355630	100	80	Hand/Snorkel
Setback Levee Ditch 2	14 June 2005	36.748090	-89.355630	100	60	Hand/Snorkel
Setback Levee Ditch 3	15 June 2005	36.709480	-89.363430	150	200	Hand/Snorkel
Setback Levee Ditch 4	15 June 2005	36.670310	-89.404100	100	150	Hand/Snorkel
Setback Levee Ditch 5	15 June 2005	36.657740	-89.416320	100	150	Hand/Snorkel
Setback Levee Ditch 6	15 June 2005	36.628780	-89.440120	100	125	Hand/Snorkel

Table 2. Freshwater mussel survey results, St. Johns Bayou Basin and Mud Ditch, Missouri.

Species	MD1	MD 2	SJoD1	SJoD 2	AD	SJaD1	SJaD 2	SJaD 3	SBL1	SBL2	SBL3	SBL4	SBL5	SBL6
Amblema plicata			8 (2)			17	189	91	13	14	49	70	65	19
Anodonta suborbiculata							0 (1)							
Arcidens confragosus							1		1	1	3	2	2	
Fusconia flava										1	2	0 (1)	0 (1)	
Lampsilis cardium			1											
Lampsilis teres						6	5	7		1	2	1	2	0 (1)
Lasmigona complanata			2 (1)			4	7	1	4	8	15	5	4	
Leptodea fragilis			1								1			3
Potamilus purpuratus			1				1		1	1 (1)	5	1	4	3
Pyganodon grandis	1					4	1 (2)		2	4	5	1	0 (1)	
Quadrula pustulosa			2						2	2	13	2	10	1
Quadrula quadrula			5				5	12	3	2	29	9	9	5
Tritogonia verrucosa			4						2	1 (1)	15		4	
Truncilla truncate												1	1	
Utterbackia imbecillis						0 (1)								
Number of Individuals (Relic)	1	0	24 (3)	0	0	31 (1)	209 (3)	111	28	35 (2)	139	92 (1)	101 (2)	31 (1)
Number of Live Species	1	0	8	0	0	4	7	4	8	10	11	9	9	5
Search Time (person hours)	0.6	0.33	2.5	0.45	1.7	1.7	1.5	0.67	1.3	1.0	3.3	2.5	2.5	2.1
CPUE Live	1.7	0	9.6	0	0	18.2	139.3	165.7	21.5	35.0	42.1	36.8	40.4	14.8

MD1 – Mud Ditch Site 1
MD2 – Mud Ditch Site 2
SJoD 1 – St. Johns Ditch 1
SJoD 2 – St. Johns Ditch 2
AD – Ash Ditch
SJaD1 – St. James Ditch 1
SJaD2 - St. James Ditch 2
SJaD3 – St. James Ditch 3
SBL1 – Setback Levee Ditch 1
SBL2 – Setback Levee Ditch 2
SBL3 – Setback Levee Ditch 3
SBL4 – Setback Levee Ditch 4
SBL5 – Setback Levee Ditch 5
SBL6 – Setback Levee Ditch 6

Table 3. Freshwater mussel surveys, habitat conditions, St. Johns Bayou Basin and Mud Ditch, Missouri.

Site	Substrate	Depth	General Habitat
Mud Ditch 1	Clay/woody debris/mud	> 3 m	Steep unstable banks, large woody debris abundant
Mud Ditch 2	Clay/woody debris/mud	> 3 m	Steep unstable banks, large woody debris abundant
St. Johns Ditch 1	Black sand	60 cm	Stable banks, thalweg along left bank
St. Johns Ditch 2	Black sand, riprap	60 cm	Stable banks, uniform depth
Ash Ditch	sand	30 cm	Clear water, filamentous algae
St. James Ditch 1	Thick silt/mud	45 cm	Stable banks, little riparian zone
St. James Ditch 2	Silt/mud, limited clay	45 cm	Stable banks, little riparian zone
St. James Ditch 3	Silt/mud, limited clay	45 cm	Stable banks, little riparian zone
Setback Levee Ditch 1	Mud/clay, sand mid-channel	60 cm	Stable banks, good riparian zone on right bank, most mussels found along toe of right bank, some mussels found on left bank where substrate consisted of mud/clay
Setback Levee Ditch 2	Mud/clay, sand mid-channel	60 cm	Stable banks, good riparian zone on right bank, most mussels found along toe of right bank, some mussels found on left bank where substrate consisted of mud/clay
Setback Levee Ditch 3	Mud/clay, sand mid-channel	60 cm	Stable banks, good riparian zone on right bank, most mussels found along toe of right bank, some mussels found on left bank where substrate consisted of mud/clay

Table 3. Continued.

Site	Substrate	Depth	General Habitat
Setback Levee Ditch 4	Mud/clay, sand mid-channel	60 cm	Stable banks, good riparian zone on right bank, most mussels found along toe of right bank, some mussels found on left bank where substrate consisted of mud/clay
Setback Levee Ditch 5	Mud/clay, sand mid-channel	60 cm	Stable banks, good riparian zone on right bank, most mussels found along toe of right bank, some mussels found on left bank where substrate consisted of mud/clay
Setback Levee Ditch 6	Mud/clay, sand mid-channel	60 cm	Stable banks, good riparian zone on right bank, most mussels found along toe of right bank, some mussels found on left bank where substrate consisted of mud/clay

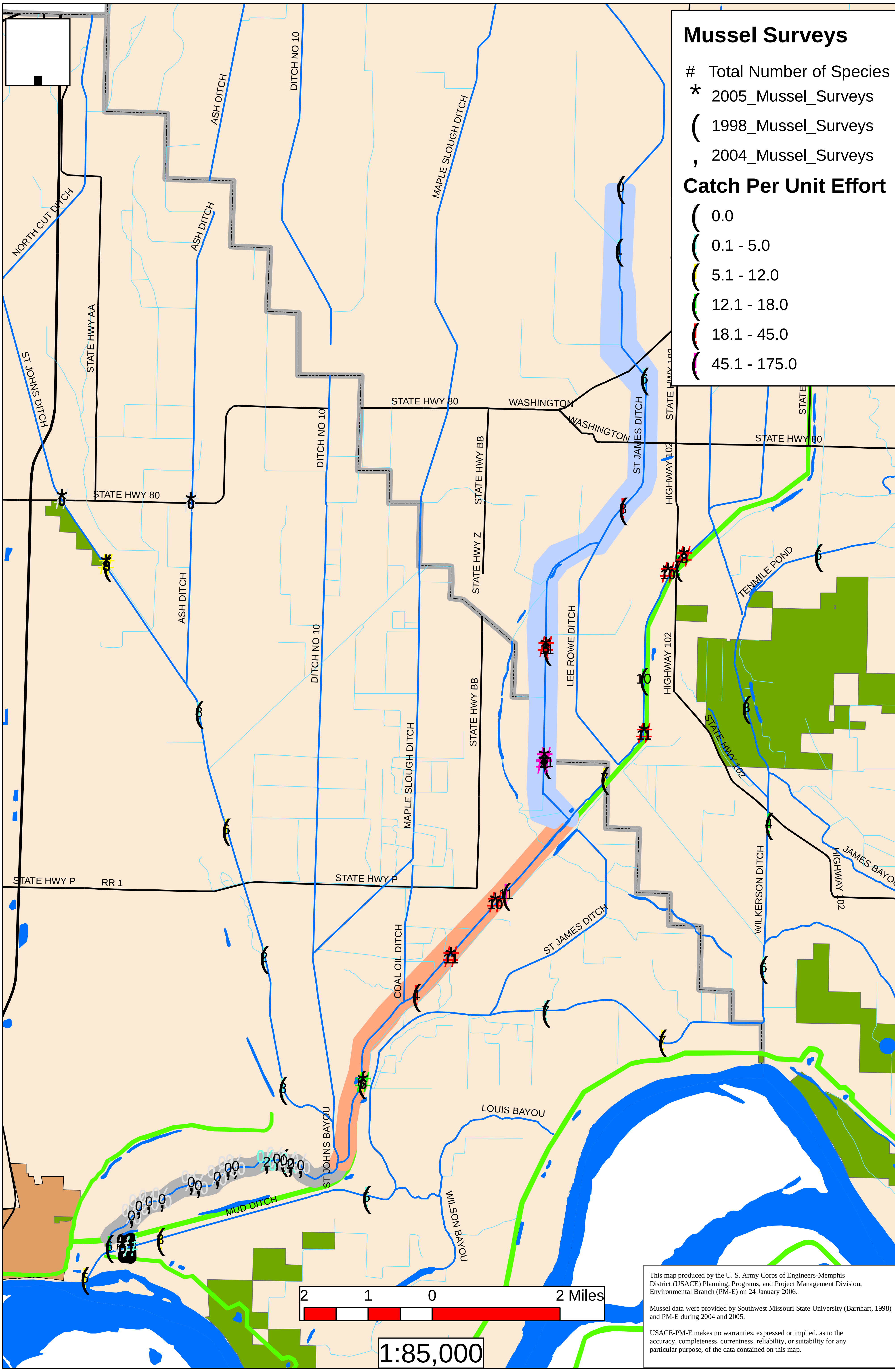

Figure 2. Freshwater mussel surveys (1998 - 2005), St. Johns Bayou Basin and the New Madrid Floodway, Missouri

Table 4. Freshwater mussel survey results from Barnhart (1998) and present survey, Mud Ditch, New Madrid Floodway, Missouri.

Species	Barnhart (1988)	Mud Ditch 1	Mud Ditch 2
Anodonta suborbiculata	1		
Leptodea fragilis	1 (1)		
Pyganadon grandis	9	1	
Number of Individuals (Relic)	11 (1)		0
CPUE Live (number/hour)	8.3	1.7	0

No mussels were found in Ash Ditch. Ash Ditch will not be used as a relocation site. No further freshwater mussel surveys of Ash Ditch are planned.

Table 5 provides a comparison of freshwater mussel species found in the Setback Levee Ditch and St. James Ditch in the present survey and those found by Barnhart (1998). The current survey found 12 and eight species of freshwater mussels in Setback Levee Ditch and St. James Ditch, respectively. Barnhart (1998) found 15 and 14 species of freshwater mussels from Setback Levee Ditch and St. James Ditch, respectively.

Setback Levee Ditch still supports a relatively diverse population of freshwater mussels throughout the construction reach. Habitat conditions were generally better in the upper reaches and decreased downstream, based on CPUE and total number of species observed. The majority of mussels collected in the upper reaches were generally found along the toe of the right descending bank. Mussels were distributed more widely throughout the entire channel bottom within the lower reaches. Proposed construction entails widening the channel to increase the bottom width by 10 feet. A nine-foot strip along the right descending bank will be avoided during construction. However, this area may become de-watered following channel excavation.

A quantitative freshwater mussel survey of Setback Levee Ditch, within the construction zone is planned. This survey will be conducted prior to construction and one year after construction to monitor the impacts of channel widening. A portion of the population will be relocated. Monitoring will continue within the construction reach over a period of 10 years to monitor recolinization rates.

The upper portions of Setback Levee Ditch, above the planned construction zone, appear to offer suitable habitat for relocated mussels. A portion of this area will be designated a control site to monitor trends in the mussel population over the next 10 years. The remaining area will be used to relocate mussels. Survivorship of this area will also be monitored.

The lower reaches of St. James Ditch support the greatest concentrations of freshwater mussels surveyed within the project area, based upon CPUE. *A. plicata* made up approximately 88% of the total mussels observed from the two lower most reaches combined. Proposed construction within the surveyed reach entails widening the bottom width by 10 feet. A portion of the population will be relocated prior to construction.

Table 5. Freshwater mussel surveys, Setback Levee Ditch and St. James Ditch, Missouri.

Species	Setback Levee Ditch (1998)	Setback Levee Ditch (2005)	St. James Ditch (1998)	St. James Ditch (2005)
Amblema plicata	X	X	X	X
Anodomta suborbiculata			X	Relic only
Arcidens confragosus	X	X	X	X
Fusconia flava	X	X		
Lampsilis cardium	X		X	
Lampsilis siliquoidea			Relic only	
Lampsilis teres	Relic only	X	X	X
Lasmigona complanata	X	X	X	X
Leptodea fragilis	X	X	X	
Ligumia subrostrata			X	
Potamilus purpuratus	X	X	X	X
Pyganodon grandis	X	X	X	X
Quadrula nodulata	X			
Quadrula pustulosa	X	X		
Quadrula quadrula	X	X		X
Toxolasma parvus			X	
Toxolasma teasensis			X	
Tritogonia verrucosa	X	X		
Truncilla truncata	X	X		
Uniomerus tetralasmus	X			
Utterbackia imbecillis			X	
Total Number of Species	15	12	14	8
Number of Sites Surveyed	6	6	5	2

Potential relocation sites were visited upstream of the construction zone on St. James Ditch. However, these sites will not be suitable because of the littering problem. A small portion of the relocated mussels from St. James Ditch will be relocated to St. Johns Bayou Ditch downstream of the Swift Ditch area (SJoD 1). Remaining mussels will be moved into the relocation area established on Setback Levee Ditch. Additional qualitative surveys will be conducted in St. James Ditch and the relocation areas to determine recolonization and survivorship.

Additional freshwater mussel surveys, including relocation efforts, will be discussed in the detailed monitoring plan. This plan will be coordinated with the interagency mitigation team made up of members from the U.S. Fish and Wildlife Service, Environmental Protection Agency, Missouri Department of Conservation, and the Missouri Department of Natural Resources.

Appendix O

Terrestrial Wildlife

U.S. Army Corps of Engineers
Memphis District

TERRESTRIAL WILDLIFE

Habitat Evaluation Procedures
Analysis and Results

IMPACT ANALYSIS

The Habitat Evaluation Procedures (HEP), USFWS (1980), was used to evaluate impacts of the St. Johns Bayou Basin and New Madrid Floodway Project on terrestrial wildlife habitat. The HEP is an accounting system for quantifying and displaying availability index (HSI) models that quantitatively describe the habitat requirements of a species or group of species. HSI models use measurements of appropriate variables to rate the habitat on a scale of zero (unsuitable) to 1.0 (optimal). Habitat units (HU) are the basic unit of HEP to measure project effects on fish and wildlife and are calculated by multiplying the evaluation species' HSI and the acreage of available habitat at a given target year. Changes in habitat quality (HSI) and quantity (i.e., acreages) are predicted for selected target years over the project's period of analysis for future without-project and future with-project conditions. Those values are then annualized over the period of analysis for the project providing average annual habitat units (AAHUs) for each of the modeled species. The difference in AAHUs under future with-project conditions and versus future without-project conditions provides a quantitative measure of project impacts. A decrease in AAHUs indicates the project will negatively affect the evaluation species; whereas, an increase in AAHUs indicates the project will benefit the evaluation species.

A subgroup of the interagency team was utilized to guide the evaluation, monitor its progress, approve assumptions and intermediate results, and make changes in direction, if needed. The subgroup, composed of biologists from USACE, USFWS, and MDC, selected eight HEP evaluation species to represent the terrestrial wildlife community utilizing three distinct habitat types in the project area: bottomland hardwood habitat (i.e., large bottomland hardwood tracts), riparian ditchbank habitat, and marsh-scrub/shrub habitat. The evaluation species for bottomland hardwood and riparian ditchbank habitats included the fox squirrel (Sciurus niger), barred owl (Stix varia), Carolina chickadee (Parus carolinensis), Pileated woodpecker (Dryocopus pileatus), and mink (Mustela vison). The evaluation species used for marsh or scrub/shrub habitats included red-winged blackbird (Agelaius phoeniceus), great blue heron (Ardea herodias), and muskrat (Ondatra zibethicus). Published HSI models were used for the fox squirrel (Allen, 1982), barred owl (Allen, 1987), pileated woodpecker (Schroeder, 1983a), mink (Allen, 1986), red-winged blackbird (Short, 1985), great blue heron (Short and Cooper, 1985), and muskrat (Allen and Hoffman, 1984). The model for the Carolina chickadee was previously developed by USFWS for projects in the region and was based on an existing model for the Black-Capped Chickadee (Parus atricapillus; Schroder, 1983b). Each of the evaluation species represented a guild (i.e., a group of species utilizing a common environmental resource); thus, habitat changes to any one of the evaluation species would be reflected on all the species within that particular guild. For example, the evaluation species: fox squirrel, barred owl, Carolina chickadee, pileated woodpecker, and mink, would also represent amphibians and reptiles normally associated with riparian ditchbank and bottomland hardwood habitats. Likewise, the evaluation species: red-winged blackbird, great blue heron, and mink, would also represent amphibians and reptiles normally associated with marsh or scrub/shrub habitats. It is also important to note that additional hydrologic impacts associated with the proposed project are addressed with other habitat models discussed in the EIS (e.g., wetlands, waterfowl, shorebirds, and fisheries).

Habitat variables were measured according to the eight selected HSI models on 12 bottomland hardwood forest plots, 12 riparian ditchbank plots, and 6 marsh scrub/shrub plots in the project area. A map of the HEP plot locations is shown in Attachment 1. Habitat variables measured for each habitat type are shown on the representative impact data sheets in Attachment 2. Each plot was 0.2 acres in area. A description of each habitat type is listed below:

Riparian Ditchbank Habitat
For this analysis, riparian ditchbank habitat was defined as those wooded lands immediately adjacent to the ditches within the project area. Most of this habitat contained various stages of vegetative growth over existing spoil piles which ranged from approximately 3 to 15 feet in height. The vegetative growth ranged from <5 years in age to > 25 years in age depending on the time since the previous cleanout. Observations of this terrestrial wildlife habitat included a dominant overstory of sugarberry and silver maple (~10-12 inches in diameter at breast height (dbh)) with a few larger (~18-24 in. dbh) cottonwoods and red oaks present. Mean dbh of the overstory trees from all HEP plots was less than 16 inches. A dense understory was also observed in this habitat type. All of the ditches adjacent to the riparian ditchbank habitats are considered perennial streams with surface water present 100% of the year; thus, the riverine version of the mink model was used for the impact anlaysis.

Bottomland Hardwood Habitat
For this analysis, bottomland hardwood habitat was defined as those contiguous bottomland hardwood tracts >1,000 acres in size. Some ditches or other bodies of water may extend throughout these habitats, but the contiguous wooded lands extend much larger distances from these bodies of water and generally contained more mature woods than the riparian ditchbank habitats. Observations of this terrestrial wildlife habitat included a dominant overstory of various oak and hickory species with a large number of sugarberry also observed. Mean dbh of the overstory trees from all HEP plots was over 19 inches. Understory was generally less dense than what was observed in the riparian ditchbank habitat. Percent of year with surface water present was calculated from the hydrologic period of record at each HEP plot location for the impact analysis. The palustrine forested (>1,000 acres) version of the mink model was used for the impact analysis of bottomland hardwood habitat.

Marsh or Scrub-Shrub Habitat
For this analysis, marsh or scrub/shrub habitat consisted of either fallow fields (most likely enrolled in WRP/CRP program) or homogenous stands of either small willows or buttonbush. Observations of the fallow fields included a dominant vegetation of cocklebur and Indian hemp. Standing water was present in only a few of the plots located in fallow fields, and each appeared to be

recently flooded (past ~1-2 weeks) from artificial hydrology. Percent of year with surface water present was calculated from the hydrologic period of record at each HEP plot location for the impact analysis. Aquatic macroinvertebrates observed in those plots with standing water included: crayfish, chironomids, backswimmers, water boatmen, predacious diving beetles, and mosquito larvae. No dragonfly larvae (odonata) were observed at any plot; thus, Condition B of the red-winged blackbird model was used for the impact analysis.

Utilizing a Geographic Information System (GIS), estimates regarding the necessary project rights-of-ways were overlaid on the land cover shapefile. Project rights-of-ways include all areas that will be necessary to conduct channel modifications (*e.g.,* enlargement, vegetative clearing, etc.) as well as necessary disposal areas for enlargement reaches. GIS was also used to determine the acreages of each cover type that falls within the proposed project right of way.

HSI scores for the three habitat types and changes in habitat type quantity were projected over the 50-year project life for future with- and future without-project conditions for both St. Johns Bayou Basin and New Madrid Basin (see Attachment 3). Assumptions made to future conditions are as follows:

- HSI scores of the impact areas were assumed to be the same over the 50-year project life for the without-project scenario. In reality, some of this riparian habitat would be cleared for maintenance purposes while other areas would continue to mature. Additionally, some areas could be harvested for timber/pulp production in the future. Due to the uncertainty of future actions, the HEP team used an unchanged overall condition in these impact areas for the without-project scenario.

- For the with-project scenario, the HEP team used a conservative assumption of a complete loss of riparian habitat after construction throughout the period of analysis even though some of the losses to the wooded riparian hardwoods would be partially regained through the grass berm on the working side of the channel, and vegetative regeneration on the spoil piles. These measures were not included in the HEP analysis due to the uncertainty of impacts associated with future maintenance.

- Construction of the project would take up to five years to complete and be conducted at different phases. Due to the uncertainty of how much construction would take place at years one and five, the HEP team assumed a complete loss of the riparian ditchbank habitat at both target years.

- Although the existing 6.8 acres of forested area cleared for construction of the closure levee was previously cleared and replanted pursuant to the Court Order, the area of impact was assumed to have the same HSI value as the riparian ditchbank habitats in the St. Johns Bayou Basin.

Authorized Project Alternative - St. Johns Bayou Improvements Only

Alternative 2.1 consists of managing flood risks in the St. Johns Bayou Basin only. The alternative consists of channel enlargement and drainage improvements along the lower 4.5 miles of St. Johns Bayou, beginning at New Madrid, Missouri, continuing along the Birds Point New Madrid Setback Levee Ditch, and ending with 10.8 miles along St. James Ditch. Selective clearing and snagging has already been completed along a 4.3-mile reach of the Setback Levee Ditch beginning at it confluence with St. James Ditch. In addition, a 1,000-cfs pumping station will be constructed a few hundred feet east of the existing gravity outlet at the lower end of St. Johns Bayou.

The lower 4.5 miles of St. Johns Bayou would be cleared and enlarged on both sides; bottom widths would be increased from approximately 80 feet to 200 feet. Approximately 2,485,000 cubic yards of material would be deposited along both banks creating a 220-foot wide embankment on each side. Following construction, the embankments would be allowed to re-vegetate naturally as part of a conservation easement.

The lower 8.1 miles of the Birds Point New Madrid Setback Levee Ditch would be enlarged from approximately 40 feet to 50 feet. The work would take place along the left descending bank and approximately 675,000 cubic yards of material would be placed in a 120-foot wide embankment located along the left descending bank. The area would be allowed to re-vegetate naturally as part of a conservation easement.

St. James Ditch would be enlarged along the left descending bank. Bottom width along the lower 3.5 miles would be enlarged from 35 feet to 45 feet. No changes to bottom width are anticipated along the remaining 7.8 miles of channel. However, top width along the left descending bank would be widened to an 80-foot average. Approximately 630,000 cubic yards of excavated material would be placed on a 100-foot wide embankment along the left descending bank. The area would be allowed to re-vegetate naturally as part of a conservation easement.

A 1,000 cfs pumping station would be constructed several hundred feet to the east of the existing gravity outlet structure on St. Johns Bayou. The pumping station would discharge interior impounded runoff over the levee during high Mississippi River stages. Pumping would commence when water in the sump area reached an elevation of 279.0 feet NGVD and would continue until the sump elevation dropped to 277.0 feet NGVD. Gates would remain closed when river stages are greater than the sump elevation, thus preventing Mississippi River backwater flooding. Gates would remain open when the sump elevation is greater than the Mississippi River elevation, thus allowing for drainage through the St. Johns Bayou gravity outlet structure. During waterfowl season (1 December to 31 January) gates would be closed to impound interior runoff in the lower St. Johns Bayou Basin for the benefit of waterfowl. Impounded interior runoff would be managed to an elevation of 285.0 NGVD by gravity drainage (stop log structure) or by turning on pumps in the event of high Mississippi River stages. Detailed descriptions of the alternatives including gate and pump management are discussed in the Alternatives Section of the EIS (Section 2.0).

Approximately 673 acres of riparian ditchbank habitat would be impacted from the clearing and associated channel work in St. Johns Bayou, Setback Levee Ditch, and St. James Ditch for the Authorized Project Alternative resulting in a loss of 1,262.73 AAHUs in the St. Johns Bayou Basin (Table 1).

Avoid and Minimize Project Alternative - St. Johns Bayou Improvements Only

The lower 4.3 miles of St. Johns Bayou would be excavated from the right descending bank only and the bottom width would be decreased from 200 feet to 120 feet. Excavated material would be placed in the project right of way along the right descending bank and would be allowed to revegetate naturally. Setback Levee Ditch would be enlarged from one side (left descending bank). The Setback Levee runs parallel to Setback Levee Ditch along the left descending bank. Therefore, existing riparian vegetation that is located along the right descending back would be preserved. Rights of way along St. James Ditch would be obtained along alternate sides to protect areas of riparian vegetation (*i.e.*, spoil material would be placed into areas that are likely prior converted cropland as opposed to vegetated areas, where practical). Detailed descriptions of the Avoid and Minimize Alternative including gate and pump management are discussed in the Alternatives Section of the EIS (Section 2.0).

The Avoid and Minimize Project Alternative would impact approximately 409 acres of riparian ditchbank habitat from the from the clearing and associated channel work in St. Johns Bayou, Setback Levee Ditch, and St. James Ditch resulting in the loss of 765.65 AAHUs in the St. Johns Bayou Basin (Table 1).

Table 1. Average Annual Habitat Units Lost by the Authorized Project Alternative and the Avoid and Minimize Project Alternative due to construction in the St. Johns Bayou Basin

Habitat Type	Authorized Project Alternative	Avoid and Minimize Project Alternative
Riparian Ditchbank	-1262.73	-765.65
Bottomland Hardwood Forest	0	0
Marsh or Scrub/shrub	0	0
Total	**-1262.73**	**-765.65**

Both Authorized Project Alternative and Avoid and Minimize Project Alternative – New Madrid Levee Closure Only

Alternative 2.2 would close the 1,500-foot levee gap at the lower end of the New Madrid Floodway between setback levee mile 35 and 37. The levee would be constructed of approximately 233,000 cubic yards of material, have a crown elevation of 317.0 feet NGVD, top width of 16 feet, base width of approximately 302 feet, and have side slopes of 4.5:1. The footprint would be approximately 9 acres of which 6.8 acres were considered forested. Four 10 by 10-foot gated box culverts would be constructed in Mud Ditch to maintain drainage in the New Madrid Floodway. Gates would be managed in a similar fashion as the existing St. Johns Bayou gravity outlet structure. Gates would be closed when the river elevation is higher than the sump elevation. Subsequently, gates would be opened when the sump elevation is greater than the river elevation.

Closing the levee gap at the lower end of the New Madrid Floodway would reduce the conveyance for flood water passage when the floodway is operated. Therefore, interior runoff would be impounded resulting in an increase to water elevation along portions of the Birds Point Setback Levee. To maintain the authorized 3-foot freeboard above the project design flood, a 14.1-mile section of the Setback Levee would require a grade raise to ensure flood protection in the St. Johns Bayou Basin at the authorized level of protection. Setback Levee grade raises range from 0.1 feet to three feet (Average 1.28 feet) and would require 2.4 million cubic yards of material. Material would be obtained from 387 acres of borrow pits that would be ecologically designed to benefit floodplain fisheries. Detailed descriptions of the alternatives including gate and pump management are discussed in the Alternatives Section of the EIS (Section 2.0).

Both the Authorized Project Alternative and the Avoid and Minimize Project Alternative would impact approximately 6.8 acres of riparian ditchbank habitat due to construction of the New Madrid Floodway levee closure resulting in a loss of 12.76 AAHUs in the New Madrid Basin (Table 2).

Table 2. Average Annual Habitat Units Lost by the Authorized Project Alternative and the Avoid and Minimize Project Alternative due to construction in the New Madrid Basin

Habitat Type	Authorized Project Alternative	Avoid and Minimize Project Alternative
Riparian Ditchbank	-12.76	-12.76
Bottomland Hardwood Forest	0	0
Marsh or Scrub/shrub	0	0
Total	**-12.76**	**-12.76**

COMPENSATION ANALYSIS

An adaptive mitigation strategy will be employed to compensate for significant unavoidable project related impacts. HSI values for any particular mitigation tract depend on the overall mitigation method and the species of vegetation restored on the site. For example, mitigation tracts with a high abundance of mast producing trees would generally result in high HSI values for fox squirrel. In contrast, mast producing trees do not tolerate long periods of inundation and therefore, would not necessarily result in high HSI values for mink. Therefore, site specific mitigation plans will be developed and submitted to the interagency team for review as mitigation lands become identified and available. Additional information can be found in Section 6.0 of the EIS.

Although site specific areas are required to be known to quantify benefits of compensatory mitigation, general assumptions can be made regarding six different mitigation zones found within the project area. Similar to the impact analysis, habitat variables (and associated HSI scores) for the six mitigation zones were projected over the 50-year project life for future with- and future without-project conditions to determine appropriate compensation for unavoidable impacts to terrestrial resources (see Attachment 4). To maintain consistency, the same evaluation species for bottomland hardwood and riparian ditchbank habitats were used in the impact analysis and compensation analysis (i.e., fox squirrel, barred owl, Carolina chickadee, pileated woodpecker, and mink). Brief descriptions of the six mitigation zones used for the HEP analysis are discussed below. Detailed descriptions of the mitigation plan are discussed in the Comparison of Alternatives Section of the EIS (Section 2.4) and the Mitigation Section of the EIS (Section 6.0).

Mitigation Zone 1:
A priority will be given to Big Oak Tree State Park. This includes increasing the footprint of the park by 1,800 acres and restoring hydrology by means of a gated structure located in the Mississippi River Frontline Levee. Restoration of the 1,800 acres includes site preparation (e.g., deep disking, sub-soiling), restoration of site-specific hydrology (e.g., plugging drainage ditches, removing farm drains, etc.) in addition to re-establishing the Mississippi River connection, restoration of microtopography (i.e., shallow excavation of deeper areas and filling higher areas to create topographical heterogeneity), and plantings of appropriate vegetation according to the site-specific hydrologic zones detailed in the Big Oak Tree State Park Natural Resource Management Plan (McCarty, 2005). Utilizing GIS, assumptions for this restoration are based on elevation data and include the following composition: 39% of the area planted with cypress/tupelo (hydrologic zone II); 5% of the area planted with cypress, pumpkin ash, and tupelo (hydrologic zone III); and 56% of the area planted with various oak and hickory species (hydrologic zones IV and V). A total of 1,744.20 AAHUs is expected by the restoration of 1,800 acres surrounding Big Oak Tree State Park for a net benefit of 0.97 AAHUs/acre (Table 3).

Although restoring hydrology to the park itself will result in changes to species composition and thus produce ecological benefits, no benefits were calculated for the restoration of hydrology to the park for this particular model. Benefits of restoring hydrology to the park are described with the fish, wetland, and waterfowl models.

Mitigation Zone 2:
This analysis includes a hypothetical 100-acre tract of land pursued within the fish and wildlife management pool (Zone 2). Restoration would include site preparation, restoration of hydrology, restoration of microtopography, and plantings of appropriate seedlings according to the site-specific hydrological regime. Assumptions for this restoration include the following composition: 50% of the area planted with cypress/tupelo seedlings, 25% of the area allowing for natural succession of herbaceous vegetation, and 25% of the area remaining in open water. A

total of 72.80 AAHUs would be gained through the restoration of a hypothetical 100-acre tract in Zone 2 for a net benefit of 0.73 AAHUs/acre (Table 3).

Mitigation Zone 3 and Zone 4:
This analysis includes a hypothetical 100-acre tract of land within Zone 3, those lands within the maximum flood elevation (i.e., lands still connected to Mississippi River or within post-project interior inundated runoff elevations), and Zone 4, those lands located at higher elevations than the post-project maximum flood elevation. Restoration would include site preparation, restoration of hydrology, restoration of microtopography, and plantings of appropriate seedlings according to the site-specific hydrological regime. Assumptions for this restoration include the following composition: 10% of area allowing for natural succession of herbaceous vegetation, 30% of area planted with drier oak/hickory species (e.g. cherrybark oak, pignut hickory, etc.), and 60% of area planted with wetter oak/hickory species (e.g. overcup oak, nuttal oak, etc.). A total of 82.15 AAHUs would be gained through the restoration of a hypothetical 100-acre tract in Zones 3 and 4 for a net benefit of 0.82 AAHUs/acre (Table 3).

Mitigation Zone 5:
This analysis includes restoration of a hypothetical 100-acre tract from cleared lands located within the batture of the Mississippi River. Assumptions for this restoration include 100% of the land reverting to cottonwood/willow communities through natural succession. A total of 80.40 AAHUs would be gained through the restoration of a hypothetical 100-acre tract in Zone 5 for a net benefit of 0.80 AAHUs/acre (Table 3).

Mitigation Zone 6:
This analysis includes a hypothetical 10-mile reach of stream which would be buffered by planting warm season grasses. Although there would be numerous benefits to terrestrial wildlife (*e.g.,* northern bobwhite quail, rabbit, etc) and water quality by the establishment of warm season grasses habitat cannot be quantified by the methods utilized in this particular model. Therefore, according to this model, establishment of warm season grass buffers on area ditches would not result in a benefit.

Table 3. Average Annual Habitat Units Gained for each Mitigation Zone in the St. Johns Basin and New Madrid Floodway Project Area

Mitigation Zone	Estimated Total Benefits (AAHUs)	AAHUs gained/acre
Zone 1	+1744.20	+0.97
Zone 2	+72.80	+0.73
Zones 3 and 4	+82.15	+0.82
Zone 5	+80.40	+0.80
Zone 6	0	0

The amount of compensatory mitigation (acreage estimates) for project-induced terrestrial habitat losses can be calculated by dividing the total AAHUs lost due to impacts of the project by the AAHUs gained/acre due to proposed mitigation (e.g., restoration of bottomland hardwoods, buffer strips, etc.). Mitigation calculations for each mitigation zone due to the Authorized Project and the Avoid and Minimize Project Alternatives are shown in Table 4.

Table 4. Calculations of compensatory mitigation estimates for project-induced terrestrial habitat losses of the Authorized Project Alternative and the Avoid and Minimize (A&M) Project Alternative for each Mitigation Zone*

Construction in St. Johns Bayou Basin						
Mitigation Zone	**Project Alternative**	**Total AAHUs lost**	÷	**Total AAHUs gained/acre**	=	**Compensatory Mitigation Amounts**
Zone 1	Authorized	1,262.73	÷	0.97	=	1,301.78 acres
	Avoid and Minimize	765.65	÷	0.97	=	789.33 acres
Zone 2	Authorized	1,262.73	÷	0.73	=	1,729.77 acres
	Avoid and Minimize	765.65	÷	0.73	=	1,048.84 acres
Zones 3 & 4	Authorized	1,262.73	÷	0.82	=	1,539.92 acres
	Avoid and Minimize	765.65	÷	0.82	=	933.72 acres
Zone 5	Authorized	1,262.73	÷	0.80	=	1,578.41 acres
	Avoid and Minimize	765.65	÷	0.80	=	957.06 acres
Zone 6	Authorized	1,262.73	÷	0	=	N/A
	Avoid and Minimize	765.65	÷	0	=	N/A
Construction in New Madrid Floodway						
Mitigation Zone	*****Project Alternative**	**Total AAHUs lost**	÷	**Total AAHUs gained/acre**	=	**Compensatory Mitigation Amounts**
Zone 1	Authorized or A&M	12.76	÷	0.97	=	13.16 acres
Zone 2	Authorized or A&M	12.76	÷	0.73	=	17.48 acres
Zones 3 & 4	Authorized or A&M	12.76	÷	0.82	=	16 acres
Zone 5	Authorized or A&M	12.76	÷	0.80	=	15.95 acres
Zone 6	Authorized or A&M	12.76	÷	0	=	N/A

*The compensatory mitigation amounts calculated in this table show the mitigation required to fully compensate for project induced terrestrial losses for each mitigation zone; however, mitigation will likely be performed utilizing a combination of multiple zones (not just one).
**The Authorized Project Alternative and the Avoid and Minimize (A&M) Project Alternative both include a closure levee (i.e., result in same impacts) in the New Madrid Floodway.

It is important to note that Table 4 shows the acreages that would be required to compensate for project-induced terrestrial habitat losses within each specific mitigation zone. However, it is anticipated that mitigation will be conducted in multiple zones with a priority given to Big Oak Tree State Park. A more detailed description of how mitigation will be pursued is discussed in the Mitigation Section of the EIS (Section 6.0).

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ERRATA

The revised analyses for the new project alternatives, 4.1 and 4.2, compared to the future without project are provided below.

Habitat Type	Alternative 4.1	Alternative 4.2
Riparian Ditchbank	-12.76	1,048.27
Bottomland Hardwood Forest	0	10,992.24
Marsh or Scrub/Schrub	0	0
Total	-12.76	12,040.51

Alternative 4 is similar to Alternative 3 in that all project features are constructed, including the 1,000 cfs St. Johns Bayou pumping station, 24 miles of reduced width channel enlargement in the St. Johns Bayou Basin, 1,500-foot closure levee, 1,500 cfs pump in the New Madrid Floodway, and waterfowl management in both basins. Alternative 4.1 calls for construction of the flood risk management features only with no additional measures to areas below an elevation of 289.5 feet. Alternative 4.2 calls for reforestation of agricultural lands below an elevation of 289.5 feet in conjunction with the structural flood risk management measures previously stated. There are 13,340 acres of agricultural lands below an elevation of 289.5 feet. Alternative 4.2 yields considerable gains in AAHU, as seen in the preceding table.

ATTACHMENTS

Attachment 1. Map of HEP plot locations

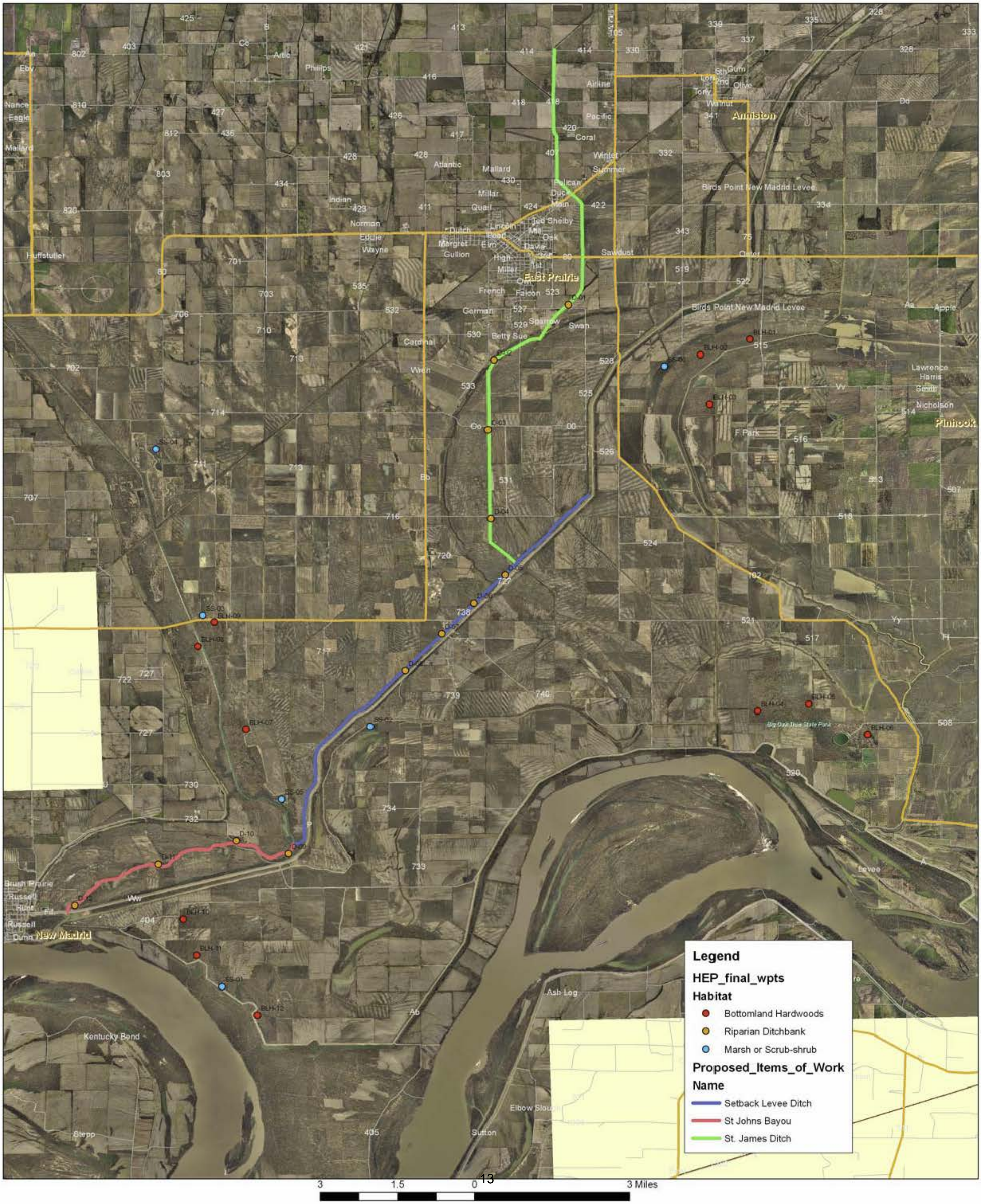
Attachment 2. Representative Data Sheets for Impact Analysis

Attachment 3. Impact Analysis

Attachment 4. Compensation Analysis

ATTACHMENT 1

SJNM Project Area - HEP Plot Locations
25-28 Oct. 2010



ATTACHMENT 2

ST. JOHNS/NEW MADRID PROJECT – HEP DATA SHEET

Site # D-06 GPS (dd.ddddd) 36.67856 Date: 26 Oct. 2010

Habitat (Cover Type): Riparian Ditchbank 89.39582 Plot size: 1/5 acre

Species – Variable#	Variable Description	Raw Data	SI Value
fs1	% canopy closure of trees that produce hard mast (e.g. oak, hickory, walnut, pecan, beech) ≥ 10 in. (25.4 cm) dbh.	5%	0.1
fs2	Distance to available grain (linear distance in yards or meters to farm fields with corn, soybeans, wheat, oats, or fruit crops).	3 yds	1.0
fs3, bo2	Mean dbh of overstory trees (i.e. trees that are ≥ 80% of the height of tallest tree in plot	12 in	0.575 0.45
fs4, cc1, pw1	% tree canopy closure of all trees (all woody vegetation ≥ 16.5 ft. (5m) tall).	75%	fs4, 0.8 cc1, 1.0 pw1 0.9
fs-5	% shrub crown cover (all woody vegetation ≤ 16.5 ft. (5m) tall).	45%	0.7
bo1, pw2	# of trees ≥ 20 in. dbh /acre (i.e. # of both living trees and/or snags that are ≥ 20 in. (51cm) dbh per 0.4 ha (~1acre)).	0	bo1, 0.1 pw2 0
bo3	% canopy cover of overstory trees (i.e. trees that are ≥ 80% of the height of tallest tree in plot	75%	1.0
cc2	Average height of overstory trees (i.e. trees that are ≥ 80% of the height of tallest tree in plot	80 ft	1.0
cc3	Combined # of living trees with ≥ 1cavity and # of snags (both have to be ≥ 10cm (4in.) dbh), per hectare (~2.5acres).	5 x 12.5 62.5	1.0
pw3	# of tree stumps > 1 ft. (0.3m) in height and > 7 in. (18cm) in diameter and/or logs > 7 in. (18cm) in diameter per acre (0.4ha). (log diameter measured at largest point).	5 x 5 25	1.0
pw4	# of snags > 15 in. (38cm) dbh / acre (0.4ha). (snags include trees which at least 50% of the branches no longer bear foliage; also have to be at least 6ft tall).	0	0
pw5	mean dbh of snags > 15 in.(38cm) dbh.	0	0
	Use for "ditch" sites (riverine model)		
mi1	% of year with surface water present	100%	1.0
mi5	% of tree and shrub canopy cover within 328 ft. (100m) of water's edge.	30%	0.4
mi6	% shoreline cover within 3.3 ft. (1m) of water's edge. (Cover may be provided by overhanging emergent vegetation, undercut banks, logjams, debris, or exposed roots.)	40%	0.4
Use for other BLH sites (palustrine forested >1,000 acres model)			
mi1	% of year with surface water present		
mi2	% tree canopy closure of all trees (all woody vegetation ≥ 20 ft. (6m) tall).		
mi3	% shrub canopy closure of all shrubs (all woody vegetation < 20 ft. (6m) tall).		
mi4	% canopy cover of emergent herbaceous vegetation (% of water surface shaded by a vertical projection of the canopies of emergent herbaceous vegetation both persistent and nonpersistent).		

Pic. 102-0049 facing N
0050 " E

ST. JOHNS/NEW MADRID PROJECT – HEP DATA SHEET

Site # BLH-06 GPS (dd.ddddd) 36.64167 Date: 28 Oct. 2010

Habitat (Cover Type): BLH 89.28543 Plot size: 1/5 acre

Species – Variable#	Variable Description	Raw Data	SI Value
fs1	% canopy closure of trees that produce hard mast (e.g. oak, hickory, walnut, pecan, beech) ≥ 10 in. (25.4 cm) dbh.	25%	0.60
fs2	Distance to available grain (linear distance in yards or meters to farm fields with corn, soybeans, wheat, oats, or fruit crops).	280 yds	0.86
fs3, bo2	Mean dbh of overstory trees (i.e. trees that are ≥ 80% of the height of tallest tree in plot	31, 30, 13 25 in	fs3 1.0 bo2 1.0
fs4, cc1, pw1	% tree canopy closure of all trees (all woody vegetation ≥ 16.5 ft. (5m) tall).	35%	fs4, 1.0 cc1, 0.5 pw1 0.2
fs-5	% shrub crown cover (all woody vegetation ≤ 16.5 ft. (5m) tall).	10%	1.0
bo1, pw2	# of trees ≥ 20 in. dbh /acre (i.e. # of both living trees and/or snags that are ≥ 20 in. (51cm) dbh per 0.4 ha (~1acre)).	15	bo1, 1.0 pw2 0.4
bo3	% canopy cover of overstory trees (i.e. trees that are ≥ 80% of the height of tallest tree in plot	10%	0
cc2	Average height of overstory trees (i.e. trees that are ≥ 80% of the height of tallest tree in plot	90 ft	1.0
cc3	Combined # of living trees with ≥ 1cavity and # of snags (both have to be ≥ 10cm (4in.) dbh), per hectare (~2.5acres).	6 + 12.5 75	1.0
pw3	# of tree stumps > 1 ft. (0.3m) in height and > 7 in. (18cm) in diameter and/or logs > 7 in. (18cm) in diameter per acre (0.4ha). (log diameter measured at largest point).	40	1.0
pw4	# of snags > 15 in. (38cm) dbh / acre (0.4ha). (snags include trees which at least 50% of the branches no longer bear foliage; also have to be at least 6ft tall).	5	0.3
pw5	mean dbh of snags > 15 in.(38cm) dbh.	23 in.	1.0
	Use for "ditch" sites (riverine model)		
mi1	% of year with surface water present		
mi5	% of tree and shrub canopy cover within 328 ft. (100m) of water's edge.		
mi6	% shoreline cover within 3.3 ft. (1m) of water's edge. (Cover may be provided by overhanging emergent vegetation, undercut banks, logjams, debris, or exposed roots.)		
Use for other BLH sites (palustrine forested >1,000 acres model)			
mi1	% of year with surface water present Check hydrologic data	15%	0.0
mi2	% tree canopy closure of all trees (all woody vegetation ≥ 20 ft. (6m) tall).	35%	0.5
mi3	% shrub canopy closure of all shrubs (all woody vegetation < 20 ft. (6m) tall).	10%	0.2
mi4	% canopy cover of emergent herbaceous vegetation (% of water surface shaded by a vertical projection of the canopies of emergent herbaceous vegetation both persistent and nonpersistent).	20%	0.3

Pic 102-0080 facing NW

ST. JOHNS/NEW MADRID PROJECT – HEP DATA SHEET

Site # SS-01 GPS (dd.ddddd) 36.57079 Date: 26 Oct. 2010

Habitat (Cover Type): Scrub-Shrub 89.46659 Plot Size: 1/5 acre
(unless otherwise noted)

Species – Variable#	Variable Description	Notes	Raw Data	SI Value
gbh-1	Distance between potential nest site (i.e. wooded tracts > 0.4 ha (1acre)) and foraging area (i.e. open water ≤ 0.5m (1.6ft) deep with huntable populations of small fish ≤ 25cm (0.20in) and a firm substrate).	Use GIS or observed distance to closest water body. None observed	0.3 km	1.0
gbh-2	Potential foraging habitat usually having shallow, clear water with a firm substrate and a huntable population of small fish = 1.0. or Potential foraging habitat not providing the desirable combination of conditions = 0.0.	Ground truth foraging areas in field.	0.0	0
gbh-3	If a disturbance-free zone ≥ 100m (328ft.) around potential foraging area (occasional vehicular traffic/ag-production is allowed) = 1.0. or Above conditions not usually met = 0.0.	Disturbance-free zone allows for roads with slow moving traffic or occasional mechanized ag-operations. HEP team will decide; likely to use 1.0 for all sites. No ponded water observed	1.0	1.0
gbh-4	If trees (within 250 m (820ft.) of water/swamp) are ≥ 5 m (16.4 ft.) tall, have many branches ≥ 2.5 cm (1 inch) in diameter, and have an open canopy allowing easy access to nest = 1.0. or if trees do not fulfill conditions above = 0.0.	Stand of willows ~3in dbh avg. is dominant veg.	0.0	0
gbh-5	If exclusion zone (250m buffer on land or 150m (492ft.) buffer on water) is usually free from human disturbances during nesting season (Feb.-Aug.) = 1.0 or If exclusion zone is usually not free from human disturbances during nesting season = 0.0	Disturbances include houses, roads, dredging, timbering, and mechanized ag-operations. HEP team will decide value for those large tracts surrounded by agriculture.	1.0	1.0
gbh-6	Distance to closest active nest site. Nest Location @ Donaldson Point from MDC. (-89.462849, 36.557717)	Use graph illustrated in model (max. distance is 25km (15.5mi.). USACE not aware of any active nest site; HEP team should provide any available data.	1.5 km	0.98
mu-1	% canopy coverage of emergent herbaceous vegetation (both persistent and non-persistent)		5%	0.1
mu-2	% of year with surface water present	Determine using the hydrologic period of record at each point.	10%	0.0

over

mu-8	% of emergent herbaceous vegetation consisting of Olney bulrush, common three-square bulrush, or cattail.		0%	0.0
rwb – Condition A (open water present, supports odonates)				
rwb-1	Emergent vegetation is old or new growth of broad-leaved monocots, (e.g. cattails) = 1.0 or Emergent vegetation is predominantly narrow-leaved monocots or other herbaceous material = 0.1	Determine from dominant species of emergent vegetation.		
rwb-2	If water is usually present in wetland throughout year = 1.0 or wetland usually dry during some portion of the year = 0.1	Determine using hydrologic period of record at each point.		
rwb-3	If carp are absent from wetland = 1.0 or if carp are present within wetland = 0.1	Carp are potentially present during overbank flood events but not likely to be prevalent during most of year. Unless observations show otherwise, use 1.0.		
rwb-4	If Odonata larvae (damselflies or dragonflies) are present in wetland = 1.0 or if odonata larvae are not present = 0.1	Use dip net along bottom of clumps of emergent herbaceous veg. for a total of 5 minutes per plot. Identify as present/absent.		
rwb-5	If wetland area contains an equal mix of emergent herbaceous vegetation and open water = 1.0 or if covered by a dense stand of emergent herbaceous vegetation = 0.3 or if area contains a few patches of emergent herbaceous vegetation and extensive areas of open water = 0.1			
rwb – Condition B (no open water present, does not support odonates)				
rwb-6	if only suitable foraging substrate is understory (i.e. midstory and/or overstory provide < 10% cover) = 0.1 or if only suitable foraging is midstory and/or overstory (i.e. midstory and/or overstory provide ≥ 10% cover) = 0.4 or if suitable foraging is a condition A wetland (i.e. open water supporting odonata within 200 m (656ft) = 0.9	Use large plot size of 200 m (656 ft.) radius for this variable. Coverage is predominantly from willows (little midstory or understory observed). Fairly homogenous site.	0.4	0.4

Notes

Homogenous stand of small willows (~3 in dbh); No standing water observed (in ~250 ft. radius)
pic 102-0055 facing N
56 facing E
57 facing S
58 facing W

ATTACHMENT 3

Impacts due to construction of the Authorized Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Fox Squirrel

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.35	235.62		673	0.35	235.62	
	1	673	0.35	235.62	235.62	0	0.00	0.00	78.54
	5	673	0.35	235.62	942.48	0	0.00	0.00	0
	15	673	0.35	235.62	2356.20	0	0.00	0.00	0.0
	25	673	0.35	235.62	2356.20	0	0.00	0.00	0.0
	50	673	0.35	235.62	5890.50	0	0.00	0.00	0.0
		Cumulative Habitat Units			11781.00	Cumulative Habitat Units			78.54
		Average Annual Habitat Units			235.62	Average Annual Habitat Units			1.57

NET IMPACT (AAHU)
-234.05

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Authorized Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Barred Owl

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.30	201.96		673	0.30	201.96	
	1	673	0.30	201.96	201.96	0	0.00	0.00	67.32
	5	673	0.30	201.96	807.84	0	0.00	0.00	0.00
	15	673	0.30	201.96	2019.60	0	0.00	0.00	0.00
	25	673	0.30	201.96	2019.60	0	0.00	0.00	0.00
	50	673	0.30	201.96	5049.00	0	0.00	0.00	0.00
		Cumulative Habitat Units			10098.00	Cumulative Habitat Units			67.32
		Average Annual Habitat Units			201.96	Average Annual Habitat Units			1.35

NET IMPACT (AAHU)
-200.61

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Authorized Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Carolina Chickadee

		Without Project				With Project			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.68	457.78		673	0.68	457.78	
	1	673	0.68	457.78	457.78	0	0.00	0.00	152.59
	5	673	0.68	457.78	1831.10	0	0.00	0.00	0.00
	15	673	0.68	457.78	4577.76	0	0.00	0.00	0.00
	25	673	0.68	457.78	4577.76	0	0.00	0.00	0.00
	50	673	0.68	457.78	11444.40	0	0.00	0.00	0.00
		Cumulative Habitat Units			22888.80	Cumulative Habitat Units			152.59
		Average Annual Habitat Units			457.78	Average Annual Habitat Units			3.05

NET IMPACT (AAHU)
-454.72

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Authorized Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Pileated Woodpecker

		Without Project				With Project			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.06	40.39		673	0.06	40.39	
	1	673	0.06	40.39	40.39	0	0.00	0.00	13.46
	5	673	0.06	40.39	161.57	0	0.00	0.00	0.00
	15	673	0.06	40.39	403.92	0	0.00	0.00	0.00
	25	673	0.06	40.39	403.92	0	0.00	0.00	0.00
	50	673	0.06	40.39	1009.80	0	0.00	0.00	0.00
		Cumulative Habitat Units			2019.60	Cumulative Habitat Units			13.46
		Average Annual Habitat Units			40.39	Average Annual Habitat Units			0.27

NET IMPACT (AAHU)
-40.12

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Authorized Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Mink

		Without Project				With Project			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.50	336.60		673	0.50	336.60	
	1	673	0.50	336.60	336.60	673	0.00	0.00	168.30
	5	673	0.50	336.60	1346.40	673	0.00	0.00	0.00
	15	673	0.50	336.60	3366.00	673	0.00	0.00	0.00
	25	673	0.50	336.60	3366.00	673	0.00	0.00	0.00
	50	673	0.50	336.60	8415.00	673	0.00	0.00	0.00
		Cumulative Habitat Units			16830.00	Cumulative Habitat Units			168.30
		Average Annual Habitat Units			336.60	Average Annual Habitat Units			3.37

NET IMPACT (AAHU)
-333.23

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Avoid and Minimize Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Fox Squirrel

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.35	235.62		673	0.35	235.62	
	1	673	0.35	235.62	235.62	264	0.35	92.40	164.01
	5	673	0.35	235.62	942.48	264	0.35	92.40	369.6
	15	673	0.35	235.62	2356.20	264	0.35	92.40	924.0
	25	673	0.35	235.62	2356.20	264	0.35	92.40	924.0
	50	673	0.35	235.62	5890.50	264	0.35	92.40	2310.0
		Cumulative Habitat Units			11781.00	Cumulative Habitat Units			4691.61
		Average Annual Habitat Units			235.62	Average Annual Habitat Units			93.83

NET IMPACT (AAHU)
-141.79

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Avoid and Minimize Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Barred Owl

		Without Project				With Project			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.30	201.96		673	0.30	201.96	
	1	673	0.30	201.96	201.96	264	0.30	79.20	140.58
	5	673	0.30	201.96	807.84	264	0.30	79.20	316.80
	15	673	0.30	201.96	2019.60	264	0.30	79.20	792.00
	25	673	0.30	201.96	2019.60	264	0.30	79.20	792.00
	50	673	0.30	201.96	5049.00	264	0.30	79.20	1,980.00
		Cumulative Habitat Units			10098.00	Cumulative Habitat Units			4,021.38
		Average Annual Habitat Units			201.96	Average Annual Habitat Units			80.43

NET IMPACT (AAHU)
-121.53

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Avoid and Minimize Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Carolina Chickadee

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.68	457.78		673	0.68	457.78	
	1	673	0.68	457.78	457.78	264	0.68	179.52	318.65
	5	673	0.68	457.78	1831.10	264	0.68	179.52	718.08
	15	673	0.68	457.78	4577.76	264	0.68	179.52	1,795.20
	25	673	0.68	457.78	4577.76	264	0.68	179.52	1,795.20
	50	673	0.68	457.78	11444.40	264	0.68	179.52	4,488.00
		Cumulative Habitat Units			22888.80	Cumulative Habitat Units			9,115.13
		Average Annual Habitat Units			457.78	Average Annual Habitat Units			182.30

NET IMPACT (AAHU)
-275.47

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Avoid and Minimize Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Pileated Woodpecker

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.06	40.39		673	0.06	40.39	
	1	673	0.06	40.39	40.39	264	0.06	15.84	28.12
	5	673	0.06	40.39	161.57	264	0.06	15.84	63.36
	15	673	0.06	40.39	403.92	264	0.06	15.84	158.40
	25	673	0.06	40.39	403.92	264	0.06	15.84	158.40
	50	673	0.06	40.39	1009.80	264	0.06	15.84	396.00
		Cumulative Habitat Units			2019.60	Cumulative Habitat Units			804.28
		Average Annual Habitat Units			40.39	Average Annual Habitat Units			16.09

NET IMPACT (AAHU)
-24.31

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction of the Avoid and Minimize Project Alternative in the St. Johns Bayou Basin
HEP Analysis - Mink

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	673	0.50	336.60		673	0.50	336.60	
	1	673	0.50	336.60	336.60	264	0.50	132.00	234.30
	5	673	0.50	336.60	1346.40	264	0.50	132.00	528.00
	15	673	0.50	336.60	3366.00	264	0.50	132.00	1320.00
	25	673	0.50	336.60	3366.00	264	0.50	132.00	1320.00
	50	673	0.50	336.60	8415.00	264	0.50	132.00	3300.00
		Cumulative Habitat Units			16830.00	Cumulative Habitat Units			6702.30
		Average Annual Habitat Units			336.60	Average Annual Habitat Units			134.05

NET IMPACT (AAHU)
-202.55

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction from either Authorized or Avoid and Minimize Project Alternatives in the New Madrid Floodway
HEP Analysis - Fox Squirrel

		Without Project				With Project			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	7	0.35	2.38		7	0.35	2.38	
	1	7	0.35	2.38	2.38	0	0.00	0.00	0.79
	5	7	0.35	2.38	9.52	0	0.00	0.00	0
	15	7	0.35	2.38	23.80	0	0.00	0.00	0.0
	25	7	0.35	2.38	23.80	0	0.00	0.00	0.0
	50	7	0.35	2.38	59.50	0	0.00	0.00	0.0
		Cumulative Habitat Units			119.00	Cumulative Habitat Units			0.79
		Average Annual Habitat Units			2.38	Average Annual Habitat Units			0.02

NET IMPACT (AAHU)
-2.36

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction from either Authorized or Avoid and Minimize Project Alternatives in the New Madrid Floodway
HEP Analysis - Barred Owl

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	7	0.30	2.04		7	0.30	2.04	
	1	7	0.30	2.04	2.04	0	0.00	0.00	0.68
	5	7	0.30	2.04	8.16	0	0.00	0.00	0.00
	15	7	0.30	2.04	20.40	0	0.00	0.00	0.00
	25	7	0.30	2.04	20.40	0	0.00	0.00	0.00
	50	7	0.30	2.04	51.00	0	0.00	0.00	0.00
		Cumulative Habitat Units			102.00	Cumulative Habitat Units			0.68
		Average Annual Habitat Units			2.04	Average Annual Habitat Units			0.01

NET IMPACT (AAHU)
-2.03

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction from either Authorized or Avoid and Minimize Project Alternatives in the New Madrid Floodway
HEP Analysis - Carolina Chickadee

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	7	0.68	4.62		7	0.68	4.62	
	1	7	0.68	4.62	4.62	0	0.00	0.00	1.54
	5	7	0.68	4.62	18.50	0	0.00	0.00	0.00
	15	7	0.68	4.62	46.24	0	0.00	0.00	0.00
	25	7	0.68	4.62	46.24	0	0.00	0.00	0.00
	50	7	0.68	4.62	115.60	0	0.00	0.00	0.00
		Cumulative Habitat Units			231.20	Cumulative Habitat Units			1.54
		Average Annual Habitat Units			4.62	Average Annual Habitat Units			0.03

NET IMPACT (AAHU)
-4.59

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction from either Authorized or Avoid and Minimize Project Alternatives in the New Madrid Floodway
HEP Analysis - Pileated Woodpecker

		Without Project				With Project			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	7	0.06	0.41		7	0.06	0.41	
	1	7	0.06	0.41	0.41	0	0.00	0.00	0.14
	5	7	0.06	0.41	1.63	0	0.00	0.00	0.00
	15	7	0.06	0.41	4.08	0	0.00	0.00	0.00
	25	7	0.06	0.41	4.08	0	0.00	0.00	0.00
	50	7	0.06	0.41	10.20	0	0.00	0.00	0.00
		Cumulative Habitat Units			20.40	Cumulative Habitat Units			0.14
		Average Annual Habitat Units			0.41	Average Annual Habitat Units			0.00

NET IMPACT (AAHU)
-0.41

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

Impacts due to construction from either Authorized or Avoid and Minimize Project Alternatives in the New Madrid Floodway
HEP Analysis - Mink

		Without Project				**With Project**			
Habitat Type	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Riparian Ditchbank	0	7	0.50	3.40		7	0.50	3.40	
	1	7	0.50	3.40	3.40	7	0.00	0.00	1.70
	5	7	0.50	3.40	13.60	7	0.00	0.00	0.00
	15	7	0.50	3.40	34.00	7	0.00	0.00	0.00
	25	7	0.50	3.40	34.00	7	0.00	0.00	0.00
	50	7	0.50	3.40	85.00	7	0.00	0.00	0.00
		Cumulative Habitat Units			170.00	Cumulative Habitat Units			1.70
		Average Annual Habitat Units			3.40	Average Annual Habitat Units			0.03

NET IMPACT (AAHU)
-3.37

NOTE: There were no project-related changes to large bottomland hardwood (BLH) tracts or Marsh/Scrub-shrub habitats; thus, those HEP results are not shown.

ATTACHMENT 4

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Fox Squirrel

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 1	0	1,800	0.00	0.00		1,800	0.00	0.00	
	1	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	5	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	15	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	25	1,800	0.00	0.00	0.00	1,800	0.46	828.00	4,140.00
	50	1,800	0.00	0.00	0.00	1,800	0.88	1,584.00	30,150.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			34,290.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			685.80
								NET BENEFIT (AAHU)	
								685.80	

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 2	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	0.33	33.00	577.50
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			577.50
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			11.55
								NET BENEFIT (AAHU)	
								11.55	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Fox Squirrel

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zones 3 & 4	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.49	49.00	245.00
	50	100	0.00	0.00	0.00	100	0.86	86.00	1,687.50
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			1,932.50
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			38.65
								NET BENEFIT (AAHU)	
								38.65	

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 5	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.17	17.00	85.00
	50	100	0.00	0.00	0.00	100	0.17	17.00	425.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			510.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			10.20
								NET BENEFIT (AAHU)	
								10.20	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Fox Squirrel

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 6	0	10	0.00	0.00		10	0.00	0.00	
	1	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	5	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	15	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	25	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	50	10	0.00	0.00	0.00	10	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Barred Owl

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 1	0	1,800	0.00	0.00		1,800	0.00	0.00	
	1	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	5	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	15	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	25	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	50	1,800	0.00	0.00	0.00	1,800	0.47	846.00	10,575.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			10,575.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			211.50

NET BENEFIT (AAHU)
211.50

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 2	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	0.07	7.00	122.50
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			122.50
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			2.45

NET BENEFIT (AAHU)
2.45

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Barred Owl

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zones 3 & 4	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	0.44	44.00	550.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			550.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			11.00

NET BENEFIT (AAHU)
11.00

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 5	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	1.00	100.00	1,250.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			1,250.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			25.00

NET BENEFIT (AAHU)
25.00

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Barred Owl

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 6	0	10	0.00	0.00		10	0.00	0.00	
	1	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	5	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	15	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	25	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	50	10	0.00	0.00	0.00	10	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Carolina Chickadee

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 1	0	1,800	0.00	0.00		1,800	0.00	0.00	
	1	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	5	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	15	1,800	0.00	0.00	0.00	1,800	0.05	90.00	450.00
	25	1,800	0.00	0.00	0.00	1,800	0.44	792.00	4,410.00
	50	1,800	0.00	0.00	0.00	1,800	0.85	1,530.00	29,025.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			33,885.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			677.70
								NET BENEFIT (AAHU)	
								677.70	

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 2	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.04	4.00	20.00
	50	100	0.00	0.00	0.00	100	0.18	18.00	315.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			335.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			6.70
								NET BENEFIT (AAHU)	
								6.70	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Carolina Chickadee

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zones 3 & 4	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.05	5.00	25.00
	25	100	0.00	0.00	0.00	100	0.40	40.00	225.00
	50	100	0.00	0.00	0.00	100	0.70	70.00	1,375.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			1,625.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			32.50
								NET BENEFIT (AAHU)	
								32.50	

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 5	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.04	4.00	20.00
	25	100	0.00	0.00	0.00	100	0.44	44.00	240.00
	50	100	0.00	0.00	0.00	100	0.92	92.00	1,700.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			1,960.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			39.20
								NET BENEFIT (AAHU)	
								39.20	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Carolina Chickadee

		Without Project				**With Project**			
Mitigation Zone	TargetYear	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 6	0	10	0.00	0.00		10	0.00	0.00	
	1	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	5	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	15	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	25	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	50	10	0.00	0.00	0.00	10	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Pileated Woodpecker

		Without Project				**With Project**			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 1	0	1,800	0.00	0.00		1,800	0.00	0.00	
	1	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	5	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	15	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	25	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	50	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

		Without Project				**With Project**			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 2	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Pileated Woodpecker

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zones 3 & 4	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
							NET BENEFIT (AAHU)		
							0.00		

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 5	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	0.24	24.00	300.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			300.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			6.00
							NET BENEFIT (AAHU)		
							6.00		

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Pileated Woodpecker

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 6	0	10	0.00	0.00		10	0.00	0.00	
	1	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	5	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	15	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	25	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	50	10	0.00	0.00	0.00	10	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Mink

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 1	0	1,800	0.00	0.00		1,800	0.00	0.00	
	1	1,800	0.00	0.00	0.00	1,800	0.00	0.00	0.00
	5	1,800	0.00	0.00	0.00	1,800	0.10	180.00	360.00
	15	1,800	0.00	0.00	0.00	1,800	0.10	180.00	1,800.00
	25	1,800	0.00	0.00	0.00	1,800	0.10	180.00	1,800.00
	50	1,800	0.00	0.00	0.00	1,800	0.10	180.00	4,500.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			8,460.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			169.20

NET BENEFIT (AAHU)
169.20

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 2	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.15	15.00	30.00
	15	100	0.00	0.00	0.00	100	0.50	50.00	325.00
	25	100	0.00	0.00	0.00	100	0.50	50.00	500.00
	50	100	0.00	0.00	0.00	100	0.50	50.00	1750.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			2605.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			52.10

NET BENEFIT (AAHU)
52.10

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project
HEP Analysis - Mink

		Without Project				**With Project**			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zones 3 & 4	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

		Without Project				**With Project**			
Mitigation Zone	TargetYear	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (acres)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 5	0	100	0.00	0.00		100	0.00	0.00	
	1	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	5	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	15	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	25	100	0.00	0.00	0.00	100	0.00	0.00	0.00
	50	100	0.00	0.00	0.00	100	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

Benefits gained from mitigation zones of the St. Johns Basin - New Madrid Floodway Project

HEP Analysis - Mink

		Without Project				With Project			
Mitigation Zone	TargetYear	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years	Area of Habitat (miles)	Habitat Suitability Index	Habitat Units	Habitat Units between target years
Zone 6	0	10	0.00	0.00		10	0.00	0.00	
	1	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	5	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	15	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	25	10	0.00	0.00	0.00	10	0.00	0.00	0.00
	50	10	0.00	0.00	0.00	10	0.00	0.00	0.00
		Cumulative Habitat Units			0.00	Cumulative Habitat Units			0.00
		Average Annual Habitat Units			0.00	Average Annual Habitat Units			0.00
								NET BENEFIT (AAHU)	
								0.00	

Appendix P
Part 1

Missouri Stream Mitigation Method

U.S. Army Corps of Engineers
Memphis District

Department of the Army
Corps of Engineers

State of Missouri
Stream Mitigation Method

Updated February 2007

COMPENSATORY STREAM MITIGATION

A. GENERAL INFORMATION:

Compensatory stream mitigation generally means the manipulation of the physical, chemical, and/or biological characteristics of a stream with the goal of repairing or replacing its natural functions. It involves the restoration, creation, enhancement or, for streams of national or state significance because of the resources they support, preservation of streams and their associated floodplains. The purpose is to compensate for unavoidable adverse impacts which remain after all appropriate and practicable avoidance and minimization have been achieved. Compensatory mitigation may be required for impacts to perennial, intermittent, and ephemeral streams and should be designed to restore, enhance, and maintain stream uses that are adversely impacted by authorized activities.

Compensatory stream mitigation is determined through the implementation of current Regulatory Guidance, best professional judgment, and through the public interest review process. This assessment method has been established to supplement current guidance, and provide a consistent rationale to determine appropriate compensatory stream mitigation for stream impacts resulting from Department of the Army permit authorizations in the State of Missouri. This method will be required when assessing mitigation for impacts to streams or rivers, and in assessing credits for stream mitigation banks. Permits specific to Section 10 activities, such as associated with dredging, will generally not require the use of this assessment method. In some cases, the evaluation of the permit application may reveal that the stream compensation measures are not practicable, constructible, or ecologically desirable, such as in enforcement cases; this determination will be made at the discretion of the Regulatory Project Manager.

Activities that constitute restoration/enhancement/preservation/creation include, but are not limited to: stream channel restoration; bank stabilization; in-stream habitat enhancement; impoundment removal; livestock exclusion devices; road crossing improvements; stream relocation; and natural buffer establishment.

1. Regulatory Authorities & Guidelines

Section 10 of the Rivers and Harbors Act of 1899: In accordance with Section 10 of the Rivers and Harbors Act of 1899, the Corps of Engineers is responsible for regulating all work in navigable waters of the United States.

Section 404 of the Clean Water Act: In accordance with Section 404 of the Clean Water Act as amended in 1977, the Corps of Engineers is responsible for regulating the discharge of dredged or fill material in waters of the United States, including wetlands. The purpose of the Clean Water Act is to restore and maintain the physical, chemical, and biological integrity of the nation's waters**.**

Section 230.10 (d) of the Section 404 (b)(1) Guidelines states that"... no discharge of dredged or fill material shall be permitted unless appropriate and practicable steps have been taken which will minimize potential adverse impacts of the discharge on the aquatic ecosystem." The Section 404 (b)(1) Guidelines require application of a sequence of mitigation -- avoidance, minimization and compensation. In other words, mitigation consists of the set of modifications necessary to avoid adverse impacts altogether, minimize the adverse impacts that are unavoidable and compensate for the unavoidable adverse impacts. Compensatory mitigation is required for unavoidable adverse impacts, which remain after all appropriate and practicable avoidance and minimization has been achieved.

Regulatory Guidance Letter (RGL) 02-02 - Guidance on Compensatory Mitigation Projects for Aquatic Resource Impacts Under the Corps Regulatory Program Pursuant to Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899. This guidance requires compensatory mitigation to replace aquatic resource functions unavoidably lost or adversely affected by authorized activities. RGL 02-02 provides important guidance on compensatory mitigation including requiring increased use of functional assessment tools, improved performance standards, and a stronger emphasis on monitoring with the purpose of improving the success of compensatory mitigation projects.

Regulatory Guidance Letter (RGL) 05-05 – Ordinary High Water Mark Identification. This document provides guidance for identifying the ordinary high water mark. RGL 05-05 applies to jurisdictional determinations for non-tidal waters under Section 404 of the Clean Water Act and under Sections 9 and 10 of the Rivers and Harbors Act of 1899.

Regulatory Guidance Letter (RGL) 06-03 – Minimum Monitoring Requirements for Compensatory Mitigation Projects Involving the Creation, Restoration, and/or Enhancement of Aquatic Resources. This document provides guidance on minimum monitoring requirements for compensatory mitigation projects, including the required content for monitoring reports.

District Mitigation and Monitoring Guidelines: These are guidelines and standard operating procedures developed by each individual District to address mitigation activities. Each Corps District has developed mitigation and monitoring procedures specific to that District. These guidelines and procedures are available on each District’s website, and are subject to review and modification as needed by each District.

B. <u>ADVERSE IMPACT FACTORS:</u>

Streams are complex ecosystems with morphological characteristics that are dependent on appropriate geomorphic dimension, pattern, and profile as well as biological and chemical integrity. They are not simply storm water conveyances. The following factors will determine the amount of mitigation credits required:

1. <u>Stream Types</u>:

Ephemeral Streams have flowing water only during and for a short duration after precipitation events in a typical year. Ephemeral streambeds are located above the water table year-round. Groundwater is not a source of water for the stream. Runoff from precipitation is the primary source of water for stream flow. Ephemeral streams typically support few aquatic organisms. When aquatic organisms are found they typically have a very short aquatic life stage.

Intermittent Streams have flowing water during certain times of the year, when ground water provides water for stream flow. During dry periods, intermittent streams may not have flowing water. Runoff from precipitation is a supplemental source of water for stream flow. The biological community of intermittent streams is composed of species that are aquatic during a part of their life history or move to perennial water sources.

Perennial Streams have flowing water year-round during a typical year. The water table is located above the streambed for most of the year. Groundwater is the primary source of water for stream flow. Runoff from precipitation is a supplemental source of water for stream flow. Perennial streams support a diverse aquatic community of organisms year round and are typically the streams that support major fisheries.

2. <u>Priority Area</u>: Priority area is a factor used to determine the importance of the stream that would be <u>impacted or used for mitigation</u>. Priority areas are influenced by the quality of the aquatic habitat potentially subject to be impacted or used for mitigation. The priority area factor will influence the amount of stream credits generated. As new technology is available, a stream may increase to a higher category on a case-by-case basis. The priority areas are divided into three categories:

Primary: These streams provide important contributions to biodiversity on an ecosystem scale or high levels of function contributing to landscape or human values. Impacts to these streams should be rigorously avoided or minimized. Compensation for impacts in these streams should emphasize replacement nearby and in the same immediate 8-digit hydrological unit code (HUC) watershed. Designated primary priority areas include:

National Wild and Scenic Rivers/Study Rivers
National Scenic Riverways
Outstanding National Resource Waters
Outstanding State Resource Waters
Approved greenway corridors
District Designated Waters
*Waters with listed Federal Endangered and Threatened species
*Designated Fish Spawning Habitat
*Mussel beds

* These areas are determined on a case by case basis in coordination with the USFWS and MDC

Secondary: Secondary priority areas include:

- Waters on the 303(d) list, impaired by sediment and nutrients.
- Adjacent to an approved mitigation bank or mitigation site
- Stream and river reaches within 0.5 mile upstream or downstream of primary priority reaches
- Stream or river reaches within high growth areas that are not ranked as primary priority areas. See appendix for District designations.

Tertiary: These areas include all other freshwater systems not ranked as primary or secondary priority.

3. <u>Existing Condition</u>: The state of the physical, chemical, and biological health of a stream at the time of an assessment, as compared to the least disturbed condition of similar streams in the ecoregion. This is a measure of the stability and functional state of a stream and the stability of the riparian buffer before project impacts.

Fully functional stream means that the physical geomorphology of the reach is stable and is representative of an appropriate stream hydrograph for the topographical setting. The biological community of a stream that is fully functional is diverse and unimpaired by excessive anthropogenic inputs.

- The stream is one that has not been channelized.
- The stream has no more than one stream impact within 0.5 mile upstream or downstream of the proposed stream impact, including culverts, pipes, or other manmade modifications (less than 30 feet of impacted section).
- The stream does not exhibit channel incision and headcutting. If necessary, this may be quantified through the determination of an appropriate entrenchment ratio and width/depth ratio at bankfull discharge relative to the unimpaired stream condition .
- The stream has at least a minimum width riparian buffer (minimum of at least 25 feet on both sides of the stream) of deep-rooted native vegetation.

The Corps, at its discretion, may designate the largest streams within an EDU or 8-digit HUC as fully functional, regardless of whether they meet the criteria above, based on the streams recreational, commercial, or water supply values. See appendix for District designations.

Moderately Functional stream means that the stability and resilience of the stream or river reach has been compromised, to a limited degree, through partial loss of one or more of the integrity functions (chemical, physical, biological). System recovery has a moderate probability of occurring naturally.

For purposes of this methodology, a stream generally will be considered moderately functional if the stream meets one or more of the following criteria:

- The stream segment is considered moderately functional if the entrenchment ratio and width/depth ratio at bankfull discharge is inappropriate relative to the unimpaired stream conditions.
- The stream shows that human-induced sedimentation and erosion is moderate.
- The stream has a moderate riparian buffer of deep-rooted vegetation present (minimum of at least 10 feet on both sides of the stream).
- The stream has no more than three stream impacts within 0.5 miles upstream of the proposed stream impact, including culverts, pipes, or other manmade modifications (with less than 100 feet of impacted section).

Functionally Impaired stream means that there is a very high loss of system stability and resilience characterized by loss of one or more integrity functions. Recovery is unlikely to occur naturally, and further damage is likely, unless restoration is undertaken.

For purposes of this methodology, a stream generally will be considered functionally impaired if one or more of the following criteria is met.

- The stream is considered functionally impaired if the reach has been channelized.
- The entrenchment ratio and width/depth ratio at bankfull discharge is inappropriate relative to the unimpaired stream condition, and the stream has degraded to a less desirable type (e.g. Rosgen Type "G" or "E")
- The stream has extensive human-induced sedimentation.
- The stream has little or no riparian buffer of deep-rooted vegetation on one or both sides of the stream.
- The stream has banks that are extensively eroded or unstable.
- The stream has five or greater stream impacts within 0.5 miles upstream of the proposed stream impact, including culverts, pipes, or other manmade modifications.

4. Duration: Duration is the amount of time adverse impacts are expected to last.

Temporary means impacts will occur within a period of less than 6 months and recovery of system integrity will follow cessation of the permitted activity, or active restoration of the site. For example, temporary structures which will be removed and site restored to pre-project contour and conditions.

Recurrent means repeated impacts of short duration. Examples: Utility crossings, where streambed and bank is restored but considers future maintenance, Reshaping/maintaining drainage ditch in an already channelized stream segment. Also, within-channel 24-hour water detention, in which the berm/weir would be considered a permanent impact, but the stormwater backing up for short periods in an undisturbed (not physically modified) channel behind the berm/weir would be considered a recurrent impact.

Permanent means project impacts will be permanent. Examples: armoring, detention, morphological change, impoundment, piping, and channelization.

5. Activity:

Armor means to riprap, bulkhead, or use other rigid methods to contain stream channels, leaving stream bed unaltered.

Below Grade (embedded) Culvert means to route a stream through pipes, box culverts, or other enclosed structures (<= 100 LF of stream to be impacted per linear transportation crossing). The below grade culverts should be designed to pass bankfull flow, and greater than bankfull flow to be passed through other culverts within the floodplain. The culvert bottom, including head-walls and toe-walls would be designed to be embedded to a depth of no less than 12-inches below ground line. If rock runs throughout the culvert area, a bottomless culvert should be used. Improperly designed culverts will be evaluated under Dominant Impact Factor for piping. Culverts should be designed to allow fish and other aquatic organism passage and allow other natural stream processes to occur unimpeded.

Clearing means the clearing or removal of streambank vegetation or other activities that reduce or eliminate the quality and functions of vegetation within riparian habitat without disturbing the existing topography or soil. Although these impacts may not be directly regulated, mitigation for these activities may be required if the impact occurs as a result of, or in association with, an activity requiring a permit.

Detention means to temporarily slow flows in a channel. Areas that are temporarily flooded due to detention structures must be designed to pass flows below bankfull stage. Impacts to the stream channel where the structure is located are considered fill, as defined below.

Fill means the permanent fill of a stream channel including the relocation of a stream channel (even if a new stream channel is constructed), or other fill activities.

Impound means to convert a stream to a lentic state with a dam or other detention/control structure, that is not designed to pass normal flows below bank-full stage. Impacts to the stream channel where the structure is located is considered fill, as defined above.

Morphologic change means to channelize, dredge, or otherwise alter the established or natural dimensions, depths, or limits of a stream corridor. This includes the creation of a concrete lined open channel, or excavation of a basin area upstream of a detention structure or dam.

Pipe means to route a stream through pipes, box culverts, or other enclosed structures.

Utility crossings mean pipeline/utility line installation methods that require temporary disturbance of the streambed. **Bridge footings** requiring fill in waters of the United States are also considered in this activity factor. This factor also includes drilled shafts, column/pier placement, cofferdams for footing/pier placement, temporary crossings and workpads.

6. <u>Linear Impact</u>: Linear impact means the length of stream, in feet, that will be impacted by a project, as authorized under Section 404 of the Clean Water Act, and for which mitigation will be required.

C. <u>MITIGATION CREDITS</u>:

<u>Net Benefit</u>: Net benefit is an evaluation of the proposed mitigation action relative to the restoration, enhancement, creation, and preservation of the chemical, biological, and physical integrity of the Nation's waters. Five stream mitigation methods are covered under these guidelines – 1) stream channel restoration / stream enhancement, 2) stream relocation, 3) riparian creation, 4) riparian enhancement / restoration, and 5) riparian preservation. ***<u>The Corps will determine, on a case-by-case basis</u>***, the net benefit of mitigation actions.

1. <u>In-Stream Work</u>

- **<u>Stream Channel Restoration / Stream Enhancement:</u>** All restored channels will generally be protected by a buffer of native vegetation. In addition, all stabilized stream banks should be protected by a buffer. This buffer will also generate riparian preservation, enhancement, restoration, or creation mitigation credit. Credit for removal of structures described below under the **Excellent** and **Good** restoration actions will be based on the documented length of reach that the structure impacts under current flow conditions. All proposed stream channel restoration / stream enhancement actions should include design criteria and explain why/how the project will benefit water quality and/or habitat.

a. Excellent stream channel restoration actions include:

1) Creating floodplains of appropriate dimensions adjacent to streams with inappropriately low width/depth ratios at bankfull discharge.
2) Private levee removal to restore floodplain functionality.
3) Restoring appropriate bankfull discharge width, stream sinuosity, entrenchment ratio, and width/depth ratio in degraded streams to referenced morphologic patterns
4) Removing dams and large weirs, pipes, culverts and other manmade in-stream structures with >50 linear feet of direct fill/impact, then restoring the stream channel to referenced, stable morphologic patterns (i.e. Replace culverts with span bridges).

b. Good stream channel restoration / stream enhancement actions include

1) Converting stream type by shaping upper slopes and stabilizing both bed and banks.
2) Restoring streambank stability in highly eroded areas.
3) Restoring in-stream channel features (i.e., riffle/run/pool/glide habitat) using methodology appropriate to stream type
4) Culverting existing road crossings in floodplains and replacing inappropriately sized/designed culverts to allow more natural flood flows.
5) Routing a stream around an existing impoundment by creating a morphologically stable and appropriate stream channel.
6) Removing weirs, pipes, culverts and other manmade in-stream structures.

c. Moderate stream channel restoration / stream enhancement actions include:

1) Stabilize stream channel in place
2) Restoring streambank stability in moderately eroded areas
3) Replacing inappropriately sized/designed culverts
4) Constructing fish ladders or adding woody debris to create fish habitat
5) Removing check dams, weirs, and other manmade in-stream structures where these structures are contributing to bank erosion or scour or blocking stream processes and aquatic organism movements.

- **Stream Relocation:** Movement/creation of a stream at a new location to allow an authorized project to be constructed in the stream's former location. In general, relocated streams must reflect the dimension, pattern, and profile indicated by a natural reference reach/condition in order to be adequate compensation for the authorized stream impact. Relocated streams will generally require vegetative protected buffers of sufficient width. This buffer will also generate riparian preservation, enhancement, restoration, or creation mitigation credit. Relocations resulting in a reduced channel length will generally require additional mitigation to replace stream functions. Relocated mitigation activities include, but are not limited to, open channel sections and in-stream features, including restoration of stream morphology. In-stream features include items such as fish ladders, riffle/run/pool/glide habitat, cross vanes, J-hook vanes, W-weirs, root wads, step pools, rock eddies, boulder clusters, grade control structures, and other features as appropriate.

2. Riparian Buffer Creation, Enhancement, Restoration, and Preservation:

- **Riparian Buffer Creation** means the manipulation of the physical, chemical, and/or biological characteristics present to develop a buffer on an upland where a buffer did not previously exist.

- **Riparian Buffer Restoration / Enhancement** means implementing rehabilitation practices within a stream riparian buffer zone to improve water quality and/or ecological function. Buffer enhancement may include increasing or improving upland and/or wetlands habitat within or adjacent to riverine systems. Restoration programs should strive to mimic the composition, density and structure of a reference reach habitat. For the purposes of these guidelines, an area will be considered as riparian buffer restoration if 51-100% of the area would require planting of vegetation to restore streambank stability and improve wildlife habitat. For the purposes of these guidelines, an area will be considered as riparian buffer enhancement if 10-50% of the area would require planting of vegetation to restore streambank stability and improve wildlife habitat.

- **Riparian Buffer Preservation** means the conservation, in its naturally occurring or present condition, of a riparian buffer to prevent its destruction, degradation, or alteration in any manner not authorized by the governing authority. For the purposes of these guidelines, an area will be considered as riparian buffer preservation if less than 10% of the area would require planting of vegetation to restore streambank stability and improve wildlife habitat.

3. Additional Riparian Improvements means restoring and/or enhancing vegetation within the riparian corridor proposed for mitigation credit as well as conducting additional improvements in the riparian corridor that have not been accounted for in this Mitigation Credit section. These additional riparian improvements may include;

- restoring or creating wetlands for purposes of improving water quality, flood storage, and increasing biodiversity in the mitigation area,
- removing substantial accumulations of trash or debris that may impair water quality in the mitigation area,
- removal of structures that disrupt the riparian community planned to be restored or enhanced in the mitigation area,
- fencing livestock from pastures, where livestock grazing activities are impacting water quality and/or stream ecological function, thereby minimizing or avoiding streambank degradation, sedimentation, and water quality problems. Livestock exclusion is normally accomplished by fencing stream corridors and can include the construction of stream crossings with controlled access and with stable and protected stream banks. No more than one livestock crossing may be planned per 1,000 linear feet of stream mitigation. The width of the livestock crossing will be deducted from the total length of the stream mitigation segment. This buffer may not be used for preservation purposes only, after cattle have been removed.

If any one of the above improvements are proposed in the mitigation area selected for restoration or enhancement, a 1.2 multiplier shall be applied to the value selected in Table 1. The use of the 1.2 multiplier will be used to calculate mitigation credits generated for additional improvements within the riparian buffer of the proposed mitigation area.

*** Requirements for Minimum Buffer Width: The minimum buffer width (MBW)** for which mitigation credit will be earned is 25 feet on one side of the stream, measured from the top of the streambank, perpendicular to the channel. Smaller buffer widths may be allowed on a case-by-case basis for small streams and consideration for a reduced buffer width will be based on issues related to construction constraints, land ownership, and land use activities (i.e. farming). If topography within a proposed stream buffer has more than a 2% slope, 2 additional feet of buffer are required for every additional percent of slope (e.g., minimum buffer width with a +10% slope is 41 feet). Buffer slope will be determined in 50-foot increments beginning at the stream bank. For the reach being buffered, degree of slope will be determined at 100-foot intervals and averaged to obtain a mean degree of slope for calculating minimum buffer width. This mean degree of slope will be used to calculate the minimum buffer width for the entire segment of stream being buffered.

Table 1 below provides appropriate Net Benefit values for the riparian creation, restoration, enhancement, and preservation mitigation worksheet. Note that on this worksheet, buffers on each bank of a given reach, generate mitigation credit separately (Stream Side A and Stream Side B).

Buffer width (on one side of the stream) Equal to or greater than	% Buffer that needs planting		
	*Buffer Creation and Restoration Exotic Removal and (51-100%)Planting	Buffer Enhancement Exotic Removal and (10-50%)Planting	Buffer Preservation (<10%)Planting
300 feet	2.8	1.4	0.7
275 feet	2.7	1.35	0.675
250 feet	2.6	1.30	0.65
225 feet	2.5	1.25	0.625
200 feet	2.4	1.2	0.60
175 feet	2.2	1.1	0.55
150 feet	2.0	1.0	0.50
125 feet	1.8	0.9	0.45
100 feet	1.6	0.8	0.4
75 feet	1.2	0.6	0.3
50 feet	0.8	0.4	0.2
25 feet (minimum width)**	0.4	0.2	0.1

Table 1. Riparian Buffer Creation, Restoration, Enhancement, and Preservation

* A minimum of Level II Monitoring is required.
** Smaller buffer widths may be allowed on a case-by-case basis for small streams and consideration for a reduced buffer width will be based on issues related to construction constraints, land ownership, and land use activities (i.e. farming).
Note: Use an additional 1.2 multiplier to calculate mitigation credits generated for buffers that will be restored or enhanced with additional improvements such as fencing livestock from the riparian buffer in actively grazed pastures, restoring or creating wetlands, removing substantial accumulations of trash, or removal of structures.

4. System Protection Credit: Additional mitigation credit may be generated if proposed riparian mitigation activities include minimum width buffers on **both** sides of a stream reach.

5. Monitoring and Adaptive Management:
Monitoring and contingency plans are actions that will be undertaken during the mitigation project to measure the level of success of the mitigation work and to correct problems or failures. All projects should include remedial actions that will achieve specified success criteria if deficiencies or failures are found during the monitoring period. Monitoring is a required component of all mitigation plans and should at a minimum, address all success criteria paragraphs.

Monitoring Level I will include only item 1 from Table 2.
Monitoring Level II will include at least two of the following items 1, 2, and 3 from Table 2 based on the project review.
Monitoring Level III will include items 1, 2 and 3 and may include item 4 from Table 2 based on the project review.

Mitigation Component (Item)	**Success (Required on action)**	**Failure**	**Action**
1. Photo Reference /Sample Site Longitudinal photos Lateral photos	No substantial aggradation, degradation or bank erosion.	Substantial aggradation degradation or bank erosion.	When substantial aggradation, degradation or bank erosion occurs, remedial actions will be planned, approved, and implemented.
2. Plant Survival Survival plots Stake counts Tree counts	$\geq$ 80% Survival within the planted plots. These plots should mimic reference reach target habitat in species composition, density and structure. *Native vegetation regeneration may be in the percentage determination.	< 80% Survival within the planted plots.	Area with less than 80% coverage of target species will be re-seeded and/or fertilized; live stakes and bare rooted trees will be planted to achieve desired densities.
3. Channel Stability Dimensions Longitudinal profiles Pebble count	Stable stream with pattern, profile and dimension of similar reference reach type. Minimal evidence of instability (down-cutting, deposition, bank erosion, increase in sands or finer substrate material).	Substantial evidence of instability.	When Substantial evidence of instability occurs, remedial actions will be planned, approved, and implemented.
4. Biological Indicators Invertebrate populations Fish populations	Population measurements remain the same or improve, and target species composition indicates a positive trend.	Population measurements and target species composition indicate a negative trend.	Reasons for failure will be evaluated and remedial action plans developed, approved, and implemented.

Table 2. General criteria used to evaluate the success or failure of activities at mitigation sites and required remedial actions to be implemented should monitoring indicate failure of component.

*Substantial or subjective determinations of success will be made by the mitigation sponsor and confirmed by the US Army Corps of Engineers.

6. Control/Protection: An appropriate real estate instrument, approved in advance by the Corps, will be required to protect the mitigation work in perpetuity. Which of the instruments below is appropriate for the subject property may vary depending on the situation.

Conservation easement means a legally binding recorded instrument approved by the District to protect and preserve mitigation sites by giving protection and enforcement rights by real estate interest to a third party.

Deed restriction means a provision in a deed limiting the use of the property and prohibiting certain uses. The District approves mitigation areas and requires deed restrictions to protect and preserve mitigation sites. If the applicant can demonstrate that the mitigation activity will occur within a right-of-way easement and if the easement will offer protection and preservation of the site, such as associated with highway projects, the credit will be considered the same as that for deed restriction of the mitigation site.

Restrictive covenant means a legal document whereby an owner of real property imposes perpetual limitations or affirmative obligations on the real property.

Conservancy means transferring fee title to a qualified, experienced, non-profit conservation organization or government agency. Non-profit organization means an entity recognized and operating under the rules of the Internal Revenue Services for non-profit purposes.

7. Mitigation Construction Timing: No additional credits are generated for this factor if the mitigation action in a reach is primarily riparian buffer preservation (<10% of buffer area would require planting of vegetation; see Table 1).

Non-Banks:
***Schedule 1*:** All mitigation is completed before the impacts occur.
***Schedule 2*:** A majority of the mitigation is completed concurrent with the impacts
***Schedule 3*:** A majority of the mitigation will be completed after the impacts occur.
Banks: Release of credits will be determined by the MBRT on a case-by-case basis.

8. Temporal Lag: A factor to compensate for the time required for a mitigation area to fully replace functions lost at the impact site. Different systems will require different times to reach levels of functional capacity level with the impact site. For example, a forested buffer would have a greater temporal lag than a grass covered buffer.

9. Mitigation Factor:

Use a mitigation factor of 0.5 for: 1) all out-of-kind aquatic resource or buffer replacements, 2) impacts not within a mitigation bank service area but proposing to go to a bank, or 3) permittee constructed mitigation proposed outside of 8-digit Hydrologic Unit Code (HUC) watershed in which the impacts occurred.

Use a mitigation factor of 1.0 for: 1) all in-kind aquatic resource or buffer replacements, 2) impacts within a mitigation bank service area and proposing to go to a bank, or 3) permittee constructed mitigation proposed within the 8-digit HUC watershed in which the impacts occurred.

Mitigation factors for in-lieu fee mitigation will be determined by each individual District.

Out-of-kind replacements replace aquatic resources or buffers of a different physical and functional type. This is appropriate when it provides more environmental benefit and is more practical by providing more ecological or watershed benefit than in-kind.
In-kind replacements are stream losses or buffer losses, which are replaced by a stream/buffer that is established, restored, enhanced, or protected of the same physical and functional type. This is required when the impacted resource is locally important.

D. DEFINITIONS:

Bankfull Discharge is the flow that is most effective at moving sediment, forming or removing bars, forming or changing bends and meanders, and doing work that results in the average morphologic characteristics of channels (Dunne and Leopold 1978). The bankfull stage is the point at which water begins to overflow onto a floodplain. Bankfull may not be at the top of the streambank in incised or entrenched streams. On average, bankfull discharge occurs approximately every 1.5 years.

Bankfull width is the width of the stream channel at bankfull discharge, as measured in a riffle section.

Channel Dimension is the stream's cross-sectional area (calculated as bankfull width multiplied by mean depth at bankfull). Changes in bankfull channel dimensions correspond to changes in the magnitude and frequency of bankfull discharge that are associated with water diversions, reservoir regulation, vegetation conversion, development, overgrazing, and other watershed changes. Stream width is a function of occurrence and magnitude of discharge, sediment transport (including sediment size and type), and the streambed and bank materials.

Channel Features: Natural streams have sequences of riffles and pools or steps and pools that maintain channel slope and stability and provide diverse aquatic habitat. A **riffle** is a bed feature where the water depth is relatively shallow and the slope is steeper than the average slope of the channel. At low flows, water moves faster over riffles, which provides oxygen to the stream. Riffles are found entering and exiting meanders and control the streambed elevation. **Pools** are located on the outside bends of meanders between riffles. The pool has a flat slope and is much deeper than the average channel depth. Step/pool sequences are found in high gradient streams. **Steps** are vertical drops often formed by large boulders or downed trees. Deep pools are found at the bottom of each step.

Entrenchment Ratio is an index value that describes the degree of vertical containment of a river channel. It is calculated as the width of the flood-prone area divided by bankfull width.

Flood-prone Area Width is measured in the field at an elevation twice-maximum depth at bankfull. Maximum depth is the difference between the bankfull stage and thalweg elevations in a riffle section. (Rosgen, 1994)

Mean Depth at Bankfull is the mean depth of the stream channel cross-section at bankfull stage as measured in a riffle section.

Ordinary High Water Mark (OHWM) is the line on the shore established by the fluctuations of water and indicated by physical characteristics such as a clear, natural line impressed on the bank, shelving, changes in the character of the soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding area.

Reference Reach/Condition: A stable stream reach generally located in the same physiographic ecoregion, climatic region, and valley type as the project that serves as the blueprint for the dimension, pattern, and profile of the channel to be restored.

Sinuosity and Stream Pattern: Stream pattern describes the view of a stream channel as seen from above. Streams are rarely straight; they tend to follow a sinuous path across a floodplain. Sinuosity of a stream is defined as the ratio of channel length/valley length. In addition to slope, the degree of sinuosity is related to channel dimensions, sediment load, stream flow, and the bed and bank materials.

Stable Stream: A naturally stable stream channel is one that maintains its dimension, pattern, and profile over time such that the stream does not degrade or aggrade. Naturally stable streams must be able to transport the sediment load supplied by the watershed. Instability occurs when scouring causes the channel to incise (degrade) or when excessive deposition causes the channel bed to rise (aggrade). (Rosgen, 1996)

Stream Enhancement – Stream rehabilitation activities undertaken to improve water quality or ecological function of a fluvial system. Enhancement activities generally will include some activities that would be required for restoration. These activities may include in-stream or streambank activities, but in total fall short of restoring one or more of the geomorphic variables: dimension, pattern and profile. Any proposed stream enhancement activity must demonstrate long-term stability.

Stream Profile: The profile of a stream refers to its longitudinal slope. At the watershed scale, channel slope generally decreases in the downstream direction with commensurate increases in stream flow and decreases in sediment size. Channel slope is inversely related to sinuosity, so steep streams have low sinuosities and flat streams have high sinuosities.

Stream Reach: The length of a stream section containing a complete riffle and pool complex. If none noted, a suitable length is usually no less than 300 feet long.

Stream Re-establishment – The manipulation of the physical, chemical, and/or biological characteristics of a stream with the goal of creating natural/historic functions to a former stream. Re-establishment results in rebuilding a former stream.

Stream Restoration or Rehabilitation – The process of converting an unstable, altered, or degraded stream corridor, including adjacent riparian zone (buffers) and flood-prone areas, to its natural stable condition considering recent and future watershed conditions. This process should be based on a reference condition/reach for the valley type and includes restoring the appropriate geomorphic dimension (cross-section), pattern (sinuosity), and profile (channel slopes), as well as reestablishing the biological and chemical integrity, including transport of the water and sediment produced by the stream's watershed in order to achieve dynamic equilibrium.

Stream Riparian Zone: A riparian zone is the area of vegetated land along each side of a stream or river that includes, but is not limited to, the floodplain. The quality of this terrestrial or wetland habitat varies depending on width and vegetation growing there. As with vegetated buffer, functions of the riparian zone include reducing floodwater velocity, filtering pollutants such as sediment, providing wildlife cover and food, and shading the stream. The ability of the riparian zones to filter pollutants that move to the stream from higher elevations results in this area being referred to as the buffer zone. The riparian zone is measured landward from the bankfull elevation on each side of a stream or river.

Stream Stabilization – The in-place stabilization of an eroding streambank. Stabilization techniques, which include primarily natural materials, like root wads and log crib structures, as well as sloping stream banks and revegetating the riparian zone may be considered for mitigation. When streambank stabilization is proposed for mitigation, the completed condition should be based on a reference condition or by methods appropriate to the stream reach.

Width/Depth Ratio is an index value that indicates the shape of the channel cross-section. It is the ratio of the bankfull width divided by the mean depth at bank-full.

APPENDIX A

A-1: Adverse Impact Factors Worksheet
A-2: In-Stream Work Worksheet
A-3: Riparian Buffer Worksheet
A-4: Stream Mitigation Bank Credit Assessment Worksheet

ADVERSE IMPACT
FACTORS FOR RIVERINE SYSTEMS WORKSHEET

<table>
<tr><td>Stream Type Impacted</td><td colspan="3">Ephemeral
0.1</td><td colspan="3">Intermittent
0.4</td><td colspan="3">Perennial
0.8</td></tr>
<tr><td>Priority Area</td><td colspan="3">Tertiary
0.1</td><td colspan="3">Secondary
0.4</td><td colspan="3">Primary
0.8</td></tr>
<tr><td>Existing Condition</td><td colspan="3">Functionally Impaired
0.1</td><td colspan="3">Moderately Functional
0.8</td><td colspan="3">Fully Functional
1.6</td></tr>
<tr><td>Duration</td><td colspan="3">Temporary
0.05</td><td colspan="3">Recurrent
0.1</td><td colspan="3">Permanent
0.3</td></tr>
<tr><td>Activity</td><td>Clearing
0.05</td><td>Utility Crossing/Bridge Footing
0.15</td><td>Below Grade Culvert
0.3</td><td>Armor
0.5</td><td>Detention
0.75</td><td>Morpho-logic Change
1.5</td><td>Impound-ment (dam)
2.0</td><td>Pipe
2.2</td><td>Fill
2.5</td></tr>
<tr><td>Linear Impact</td><td><100’
0</td><td>100’-200’
0.05</td><td>201-500’
0.1</td><td>501-1000’
0.2</td><td colspan="5">>1000 linear feet (LF)
0.1 reach 500 LF of impact (example: scaling factor for 5,280 LF of impacts = 1.1)</td></tr>
</table>

Factor	Dominant Impact Type 1	Dominant Impact Type 2	Dominant Impact Type 3	Dominant Impact Type 4	Dominant Impact Type 5
Stream Type Impacted					
Priority Area					
Existing Condition					
Duration					
Activity					
Linear Impact					
Sum of Factors	M =				
Linear Feet of Stream Impacted in Reach	LF=				
M X LF					

Total Mitigation Credits Required * = (M X LF) = ___________________

*This value may be applied to mitigation at a mitigation bank at a 1:1 ratio, when the impact area is within the service area of an approved mitigation bank. An increased multiplier will be used at the Corps discretion when an impact occurs outside of the service area of an approved mitigation bank, or when mitigation is proposed through an in-lieu fee program.

IN-STREAM WORK
STREAM CHANNEL / STREAM RESTORATION or ENHANCEMENT AND RELOCATION WORKSHEET

Stream Type	Ephemeral 0.05	Intermittent 0.4	Perennial Stream <15' 0.4	15'-30' 0.6	30'-50' 0.8	>50' 1.0
Priority Area	Tertiary 0.05		Secondary 0.2		Primary 0.4	
Existing Condition	Not Applicable 0		Functionally Impaired 0.4		Moderately Functional 0.05	
Net Benefit	Stream Relocation 0.1	Stream Channel Restoration / Stream Enhancement Relocated Stream with In-Stream features 0.5	Moderate 1.0		Good 2.0	Excellent 3.5
Monitoring/ Contingency	Level I 0.05			Level II 0.3	Level III 0.5	
Control / Site Protection	Corps approved site protection without third party grantee 0.1			Corps approved site protection recorded with third party grantee, or transfer of title to a conservancy 0.4		
Mitigation Construction Timing	Schedule 1 0.3			Schedule 2 0.1	Schedule 3 0	

Factors	Net Benefit 1	Net Benefit 2	Net Benefit 3	Net Benefit 4	Net Benefit 5	Net Benefit 6
Stream Type						
Priority Area						
Existing Condition						
Net Benefit						
Monitoring/Contingency						
Control/Site Protection						
Mitigation Construction Timing						
Sum Factors (M)=						
Stream length in Reach (do not count each bank separately) (LF)=						
Credits (C) = M X LF						
Total Credits Generated C X Mitigation Factor (MF) =						

Total Channel Restoration/Relocation Credits Generated = ____________

RIPARIAN BUFFER CREATION, ENHANCEMENT, RESTORATION AND PRESERVATION WORKSHEET

<table>
<tr><td>Stream Type</td><td>Ephemeral
0.05</td><td colspan="2">Intermittent
0.2</td><td colspan="3">Perennial
0.4</td></tr>
<tr><td>Priority Area</td><td>Tertiary
0.05</td><td colspan="2">Secondary
0.2</td><td colspan="3">Primary
0.4</td></tr>
<tr><td>Net Benefit (for each side of stream</td><td>Additional Improvements (select values from Table 1 times 1.2 multiplier)</td><td colspan="5">Riparian Creation, Enhancement, Restoration, and Preservation Factors
(select values from Table 1)
(MBW = Minimum Buffer Width = 25’ + 2’ / 1% slope)</td></tr>
<tr><td>System Protection Credit</td><td colspan="6">Condition : MBW restored or protected on both streambanks
To calculate:(Net Benefit Stream Side A + Net Benefit Stream Side B) / 2</td></tr>
<tr><td>Monitoring/ Contingency (for each side of stream)</td><td>Level I
0.05</td><td colspan="2">Level II
0.15</td><td colspan="3">Level III
0.25</td></tr>
<tr><td>Control / Site Protection</td><td colspan="3">Corps approved site protection without third party grantee
0.05</td><td colspan="3">Corps approved site protection recorded with third party grantee, or transfer of title to a conservancy
0.2</td></tr>
<tr><td>Mitigation Construction Timing (for each side of stream)</td><td colspan="3">Schedule 1
0.15</td><td colspan="2">Schedule 2
0.05</td><td>Schedule 3
0</td></tr>
<tr><td>Temporal Lag (Years)</td><td>Over 20
-0.3</td><td colspan="2">10 to 20
-0.2</td><td colspan="2">5 to 10
-0.1</td><td>0 to 5
0</td></tr>
</table>

<table>
<tr><td colspan="2">Factors</td><td>Net Benefit 1</td><td>Net Benefit 2</td><td>Net Benefit 3</td><td>Net Benefit 4</td><td>Net Benefit 5</td><td>Net Benefit 6</td></tr>
<tr><td colspan="2">Stream Type</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Priority Area</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Net Benefit</td><td>Stream Side A</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Stream Side B</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">System Protection Credit
Condition Met (Buffer on both sides)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Monitoring/ Contingency</td><td>Stream Side A</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Stream Side B</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Control /Site Protection</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Mitigation Construction Timing (none for primarily riparian preservation) < 10% requires planting)</td><td>Stream Side A</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Stream Side B</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Temporal Lag</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Sum Factors (M)=</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Linear Feet of Stream Buffer (LF)=
(don’t count each bank separately)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Credits (C) =M X LF</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total Credits Generated
C X Mitigation Factor (MF) =</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Total Riparian Restoration Credits Generated = ___________________

Data Form

STREAM MITIGATION BANK CREDIT ASSESSMENT WORKSHEET

Stream Type	Ephemeral 0.1	Intermittent 0.6	Perennial			
			<15' 0.8	15'-30' 1.0	30'-50' 1.2	>50' 1.4
Priority Area	Tertiary 0.1	Secondary 0.4	Primary 0.8			
Net Benefit [Riparian (for each side of stream)]	Additional Improvements (select values from Table 1 times 1.2 multiplier)	Riparian Creation, Enhancement, Restoration, and Preservation Factors (select values from Table 1) (MBW = Minimum Buffer Width = 25' + 2' / 1% slope)				
System Protection Credit	Condition : MBW restored or protected on both streambanks To calculate:(Net Benefit Stream Side A + Net Benefit Stream Side B) / 2					
Net Benefit (Stream)	Moderate 1.0	Good 2.0		Excellent 3.5		
Monitoring/ Contingency (for each side of stream)	Level I 0.075	Level II 0.3		Level III 0.5		
Control /Site Protection	Corps approved site protection without third party grantee 0.075	Corps approved site protection recorded with third party grantee, or transfer of title to a conservancy 0.3				

Factors		Net Benefit 1	Net Benefit 2	Net Benefit 3	Net Benefit 4	Net Benefit 5	Net Benefit 6
Stream Type							
Priority Area							
Net Benefit (Riparian)	Stream Side A						
	Stream Side B						
System Protection Credit Condition Met (Buffer on both sides)							
Net Benefit (Stream)							
Monitoring/ Contingency	Stream Side A						
	Stream Side B						
Control /Site Protection	Stream Side A						
	Stream Side B						
Sum Factors (M)=							
Linear Feet of Stream Buffer (LF)= (don't count each bank separately)							
Total Credits (C) =M X LF							

Total Credits Generated = ____________________

APPENDIX B
District Designations

<u>Priority Area</u>
High growth areas - Stream and river reaches within these areas that are not ranked as primary priority areas, are automatically ranked as secondary priority areas.

<u>Kansas City District Designated Areas:</u>

<u>Little Rock District Designated Areas:</u>

<u>Memphis District Designated Areas:</u>

<u>Rock Island District Designated Areas:</u>

<u>St. Louis District Designated Areas:</u>

<u>Existing Condition</u>
Large streams within EDU or 8-digit HUC automatically designated as fully functional.

<u>Kansas City District Designated Streams:</u>

<u>Little Rock District Designated Streams:</u>

<u>Memphis District Designated Streams:</u>

<u>Rock Island District Designated Streams:</u>

<u>St. Louis District Designated Streams:</u>

APPENDIX C
C-1: References

References:

Clean Water Act, Section 404

Compensatory Mitigation, Little Rock District, Regulatory Branch, US Army Corps of Engineers, Standard Operating Procedure

Department of the Army, Charleston District, Corps of Engineers, Standard Operating Procedure, Compensatory Mitigation

Department of the Army, Mobile District, Corps of Engineers, Standard Operation Procedure, Compensatory Stream Mitigation Guidelines

Department of the Army, Savannah District, Corps of Engineers, Standard Operating Procedure, Compensatory Mitigation, Wetlands, Openwater, & Streams

Department of the Army, Wilmington District, Corps of Engineers, Stream Mitigation Guidelines

Rivers and Harbors Act of 1899, Section 10

Rosgen, David L., Wildland Hydrology, March 2005

US Army Corps of Engineers, Regulatory Guidance Letters

Appendix P
Part 2

Adverse Stream Impacts

U.S. Army Corps of Engineers
Memphis District

ADVERSE IMPACT
FACTORS FOR RIVERINE SYSTEMS WORKSHEET SHEET 1 ST. JOHNS

Stream Type Impacted	Ephemeral 0.1			Intermittent 0.4			Perennial 0.8		
Priority Area	Tertiary 0.1			Secondary 0.4			Primary 0.8		
Existing Condition	Functionally Impaired 0.1			Moderately Functional 0.8			Fully Functional 1.6		
Duration	Temporary 0.05			Recurrent 0.1			Permanent 0.3		
Activity	Clearing 0.05	Utility Crossing/Bridge Footing 0.15	Below Grade Culvert 0.3	Armor 0.5	Detention 0.75	Morpho-logic Change 1.5	Impound-ment (dam) 2.0	Pipe 2.2	Fill 2.5
Linear Impact	<100' 0	100'-200' 0.05	201-500' 0.1	501-1000' 0.2	>1000 linear feet (LF) 0.1 reach 500 LF of impact (example: scaling factor for 5,280 LF of impacts = 1.1)				

Factor	Dominant Impact Type 1	Dominant Impact Type 2	Dominant Impact Type 3	Dominant Impact Type 4	Dominant Impact Type 5
Stream Type Impacted	0.8	0.8	0.8	0.8	0.8
Priority Area	0.1	0.1	0.1	0.1	0.1
Existing Condition	0.1	0.1	0.1	0.1	0.1
Duration	0.3	0.3	0.1	0.1	0.3
Activity	1.5	1.5	1.5	1.5	1.5
Linear Impact	2.6	1.3	8.6	3.7	0.1
Sum of Factors	M = 5.4	4.1	11.2	6.3	2.9
Linear Feet of Stream Impacted in Reach	LF= 12,950.0	6,450.0	43,150.0	18,480.0	450.0
M X LF	69,800.5	26,380.5	484,574.5	116,350.1	1,305.0

Total Mitigation Credits Required * = (M X LF) = SEE SHEET 2

*This value may be applied to mitigation at a mitigation bank at a 1:1 ratio, when the impact area is within the service area of an approved mitigation bank. An increased multiplier will be used at the Corps discretion when an impact occurs outside of the service area of an approved mitigation bank, or when mitigation is proposed through an in-lieu fee program.

ADVERSE IMPACT
FACTORS FOR RIVERINE SYSTEMS WORKSHEET   SHEET 2   ST. JOHNS

Stream Type Impacted	Ephemeral 0.1			Intermittent 0.4			Perennial 0.8		
Priority Area	Tertiary 0.1			Secondary 0.4			Primary 0.8		
Existing Condition	Functionally Impaired 0.1			Moderately Functional 0.8			Fully Functional 1.6		
Duration	Temporary 0.05			Recurrent 0.1			Permanent 0.3		
Activity	Clearing 0.05	Utility Crossing/Bridge Footing 0.15	Below Grade Culvert 0.3	Armor 0.5	Detention 0.75	Morpho-logic Change 1.5	Impound-ment (dam) 2.0	Pipe 2.2	Fill 2.5
Linear Impact	<100' 0	100'-200' 0.05	201-500' 0.1	501-1000' 0.2	>1000 linear feet (LF) 0.1 reach 500 LF of impact (example: scaling factor for 5,280 LF of impacts = 1.1)				

Factor	Dominant Impact Type ~~1~~ 6	Dominant Impact Type ~~2~~ 7	Dominant Impact Type ~~3~~ 8	Dominant Impact Type ~~4~~ 9	Dominant Impact ~~Type 5~~
Stream Type Impacted	0.8	0.8	0.8	0.8	
Priority Area	0.1	0.1	0.1	0.1	
Existing Condition	0.1	0.1	0.1	0.1	
Duration	0.3	0.3	0.3	0.3	
Activity	0.5	0.5	0.5	0.5	
Linear Impact	0.05	0.1	0.1	0.1	
Sum of Factors	M = 1.9	1.9	1.9	1.9	
Linear Feet of Stream Impacted in Reach	LF= 150	200	175	150	
M X LF	277.5	380.0	332.5	285.0	

Total Mitigation Credits Required * = (M X LF) = 699,685.6

*This value may be applied to mitigation at a mitigation bank at a 1:1 ratio, when the impact area is within the service area of an approved mitigation bank. An increased multiplier will be used at the Corps discretion when an impact occurs outside of the service area of an approved mitigation bank, or when mitigation is proposed through an in-lieu fee program.

ADVERSE IMPACT
FACTORS FOR RIVERINE SYSTEMS WORKSHEET

NEW MADRID

Stream Type Impacted	Ephemeral 0.1			Intermittent 0.4			Perennial 0.8		
Priority Area	Tertiary 0.1			Secondary 0.4			Primary 0.8		
Existing Condition	Functionally Impaired 0.1			Moderately Functional 0.8			Fully Functional 1.6		
Duration	Temporary 0.05			Recurrent 0.1			Permanent 0.3		
Activity	Clearing 0.05	Utility Crossing/Bridge Footing 0.15	Below Grade Culvert 0.3	Armor 0.5	Detention 0.75	Morpho -logic Change 1.5	Impound-ment (dam) 2.0	Pipe 2.2	Fill 2.5
Linear Impact	<100' 0	100'-200' 0.05	201-500' 0.1	501-1000' 0.2	>1000 linear feet (LF) 0.1 reach 500 LF of impact (example: scaling factor for 5,280 LF of impacts = 1.1)				

Factor	Dominant Impact Type 1	Dominant Impact Type 2	Dominant Impact Type 3	Dominant Impact Type 4	Dominant Impact Type 5
Stream Type Impacted	0.8				
Priority Area	0.1				
Existing Condition	0.1				
Duration	0.3				
Activity	2.2				
Linear Impact	302				
Sum of Factors	M = 3.6				
Linear Feet of Stream Impacted in Reach	LF= 302				
M X LF	1,087.2				

Total Mitigation Credits Required * = (M X LF) = 1,087.2

*This value may be applied to mitigation at a mitigation bank at a 1:1 ratio, when the impact area is within the service area of an approved mitigation bank. An increased multiplier will be used at the Corps discretion when an impact occurs outside of the service area of an approved mitigation bank, or when mitigation is proposed through an in-lieu fee program.

Appendix P
Part 3

In Stream Work and Riparian Buffer Creation

U.S. Army Corps of Engineers
Memphis District

IN-STREAM WORK
STREAM CHANNEL / STREAM RESTORATION or ENHANCEMENT AND RELOCATION WORKSHEET

ST. JOHNS

Stream Type	Ephemeral 0.05	Intermittent 0.4	Perennial Stream			
			<15' 0.4	15'-30' 0.6	30'-50' 0.8	>50' 1.0
Priority Area	Tertiary 0.05		Secondary 0.2		Primary 0.4	
Existing Condition	Not Applicable 0		Functionally Impaired 0.4		Moderately Functional 0.05	
Net Benefit	Stream Relocation 0.1	Stream Channel Restoration / Stream Enhancement				
		Relocated Stream with In-Stream features 0.5	Moderate 1.0		Good 2.0	Excellent 3.5
Monitoring/ Contingency	Level I 0.05		Level II 0.3		Level III 0.5	
Control / Site Protection	Corps approved site protection without third party grantee 0.1		Corps approved site protection recorded with third party grantee, or transfer of title to a conservancy 0.4			
Mitigation Construction Timing	Schedule 1 0.3		Schedule 2 0.1		Schedule 3 0	

Factors	Net Benefit 1	Net Benefit 2	Net Benefit 3	Net Benefit 4	Net Benefit 5	Net Benefit 6
Stream Type	1.0	1.0	0.8	0.6		
Priority Area	0.05	0.05	0.05	0.05		
Existing Condition	0.4	0.4	0.4	0.4		
Net Benefit	2.0	2.0	1.0	1.0		
Monitoring/Contingency	0.3	0.3	0.3	0.3		
Control/Site Protection	0.4	0.4	0.4	0.4		
Mitigation Construction Timing	0.1	0.1	0.1	0.1		
Sum Factors (M)=	4.25	4.25	3.05	2.85		
Stream length in Reach (do not count each bank separately) (LF)=	12,950.0	6,450.0	43,150.0	59,664.0		
Credits (C) = M X LF	55,037.5	27,412.5	131,607.5	170,042.4		
Total Credits Generated C X Mitigation Factor (MF) =	55,037.5	27,412.5	131,607.5	170,042.4		

Total Channel Restoration/Relocation Credits Generated = 384,099.9

RIPARIAN BUFFER CREATION, ENHANCEMENT, RESTORATION AND PRESERVATION WORKSHEET

ST. JOHNS

Stream Type	Ephemeral 0.05	Intermittent 0.2	Perennial 0.4	
Priority Area	Tertiary 0.05	Secondary 0.2	Primary 0.4	
Net Benefit (for each side of stream	Additional Improvements (select values from Table 1 times 1.2 multiplier)	Riparian Creation, Enhancement, Restoration, and Preservation Factors (select values from Table 1) (MBW = Minimum Buffer Width = 25' + 2' / 1% slope)		
System Protection Credit	Condition : MBW restored or protected on both streambanks To calculate:(Net Benefit Stream Side A + Net Benefit Stream Side B) / 2			
Monitoring/ Contingency (for each side of stream)	Level I 0.05	Level II 0.15	Level III 0.25	
Control / Site Protection	Corps approved site protection without third party grantee 0.05		Corps approved site protection recorded with third party grantee, or transfer of title to a conservancy 0.2	
Mitigation Construction Timing (for each side of stream)	Schedule 1 0.15		Schedule 2 0.05	Schedule 3 0
Temporal Lag (Years)	Over 20 -0.3	10 to 20 -0.2	5 to 10 -0.1	0 to 5 0

Factors		Net Benefit 1	Net Benefit 2	Net Benefit 3	Net Benefit 4	Net Benefit 5	Net Benefit 6
Stream Type		0.4	0.4	0.4	0.4	0.4	0.2
Priority Area		0.05	0.05	0.05	0.05	0.05	0.05
Net Benefit	Stream Side A	0.4	0.4	0.4	0.4	0.4	0.4
	Stream Side B	0	0	0	0	0	0
System Protection Credit Condition Met (Buffer on both sides)		0.2	0.2	0.2	0.2	0.2	0.2
Monitoring/ Contingency	Stream Side A	0.15	0.15	0.15	0.15	0.15	0.15
	Stream Side B	0	0	0	0	0	0
Control /Site Protection		0.2	0.2	0.2	0.2	0.2	0.2
Mitigation Construction Timing (none for primarily riparian preservation) < 10% requires planting)	Stream Side A	0.05	0.05	0.05	0.05	0.05	0.05
	Stream Side B	0	0	0	0	0	0
Temporal Lag		-0.2	-0.2	0	0	-0.2	0
Sum Factors (M)=		1.25	1.25	1.45	1.45	1.25	1.25
Linear Feet of Stream Buffer (LF)= (don't count each bank separately)		12,950	6,450	43,150	59,664	14,658.7	99,250
Credits (C) =M X LF		16,187.5	8062.5	62,567.5	86,512.8	18,323.4	124,062.5
Total Credits Generated C X Mitigation Factor (MF) =		16,187.5	8,062.5	62,567.5	86,512.8	18,323.4	124,062.5

Total Riparian Restoration Credits Generated = 315,716.2

RIPARIAN BUFFER CREATION, ENHANCEMENT, RESTORATION AND PRESERVATION WORKSHEET

NEW MADRID

Stream Type	Ephemeral 0.05	Intermittent 0.2	Perennial 0.4	
Priority Area	Tertiary 0.05	Secondary 0.2	Primary 0.4	
Net Benefit (for each side of stream	Additional Improvements (select values from Table 1 times 1.2 multiplier)	Riparian Creation, Enhancement, Restoration, and Preservation Factors (select values from Table 1) (MBW = Minimum Buffer Width = 25' + 2' / 1% slope)		
System Protection Credit	Condition : MBW restored or protected on both streambanks To calculate:(Net Benefit Stream Side A + Net Benefit Stream Side B) / 2			
Monitoring/ Contingency (for each side of stream)	Level I 0.05	Level II 0.15	Level III 0.25	
Control / Site Protection	Corps approved site protection without third party grantee 0.05		Corps approved site protection recorded with third party grantee, or transfer of title to a conservancy 0.2	
Mitigation Construction Timing (for each side of stream)	Schedule 1 0.15		Schedule 2 0.05	Schedule 3 0
Temporal Lag (Years)	Over 20 -0.3	10 to 20 -0.2	5 to 10 -0.1	0 to 5 0

Factors		Net Benefit 1	Net Benefit 2	Net Benefit 3	Net Benefit 4	Net Benefit 5	Net Benefit 6
Stream Type		0.4					
Priority Area		0.05					
Net Benefit	Stream Side A	0.4					
	Stream Side B	0					
System Protection Credit Condition Met (Buffer on both sides)		0.2					
Monitoring/ Contingency	Stream Side A	0.15					
	Stream Side B	0					
Control /Site Protection		0.2					
Mitigation Construction Timing (none for primarily riparian preservation) < 10% requires planting)	Stream Side A	0.05					
	Stream Side B	0					
Temporal Lag		-0.2					
Sum Factors (M)=		1.25					
Linear Feet of Stream Buffer (LF)= (don't count each bank separately)		5,799.1					
Credits (C) =M X LF		7,248.9					
Total Credits Generated C X Mitigation Factor (MF) =		7,248.9					

Total Riparian Restoration Credits Generated = 7,248.9